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AMERICAN INSTITUTE OF CROP ECOLOGY
A RESEARCH ORGANIZATION DEVOTED TO PROBLEMS OF
PLANT ADAPTATION AND INTRODUCTION
WASHINGTON, D. C.

AICE* SURVEY OF USSR AIR POLLUTION LITERATURE

Volume VII

MEASUREMENTS OF DISPERSAL AND CONCENTRATION, IDENTIFICATION, AND SANITARY EVALUATION OF VARIOUS AIR POLLUTANTS, WITH SPECIAL REFERENCE TO THE ENVIRONS OF ELECTRIC POWER PLANTS AND FERROUS METALLURGICAL PLANTS

Edited by

M. Y. Nuttonson

The material presented here is part of a survey of
USSR literature on air pollution
conducted by the Air Pollution Section
AMERICAN INSTITUTE OF CROP ECOLOGY

This survey is being conducted under GRANT No. R01 AP00786 - APC
AIR POLUTION CONTROL OFFICE
of the
ENVIRONMENTAL PROTECTION AGENCY

NATIONAL TECHNICAL
INFORMATION SERVICE

*AMERICAN INSTITUTE OF CROP ECOLOGY
809 DALE DRIVE
SILVER SPRING, MARYLAND 20910

1971

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3 CZECHOSLOVAKIA—Agricultural Climatology of Czechoslovakia and Its Agro-Climatic Analogues in North America

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6 ALBANIA—Ecological Plant Geography of Albania, Its Agricultural Crops and Some North American Climatic Analogues

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15 [illegible] ISLANDS—Ecological Crop Geography and Field Practices of the [illegible], Natural Vegetation of the [illegible], and Agro-Climatic Analogues in the Northern Hemisphere

16 PHENOLOGY AND THERMAL ENVIRONMENT AS A MEANS OF A PHYSIOLOGICAL CLASSIFICATION OF WHEAT VARIETIES AND FOR PREDICTING MATURITY DATES OF WHEAT
(Based on Data of Czechoslovakia and of Some Thermally Analogous Areas of Czechoslovakia in the United States Pacific Northwest)

17 WHEAT-CLIMATE RELATIONSHIPS AND THE USE OF PHENOLOGY IN ASCERTAINING THE THERMAL AND PHOTOTHERMAL REQUIREMENTS OF WHEAT
(Based on Data of North America and Some Thermally Analogous Areas of North America in the Soviet Union and in Finland)

18 A COMPARATIVE STUDY OF LOWER AND UPPER LIMITS OF TEMPERATURE IN MEASURING THE VARIABILITY OF DAY-DEGREE SUMMATIONS OF WHEAT, BARLEY, AND RYE

19 BARLEY-CLIMATE RELATIONSHIPS AND THE USE OF PHENOLOGY IN ASCERTAINING THE THERMAL AND PHOTOTHERMAL REQUIREMENTS OF BARLEY

20 RYE-CLIMATE RELATIONSHIPS AND THE USE OF PHENOLOGY IN ASCERTAINING THE THERMAL AND PHOTOTHERMAL REQUIREMENTS OF RYE

21 AGRICULTURAL ECOLOGY IN SUBTROPICAL REGIONS

[illegible] [illegible]—Physical Environment and [illegible]

[illegible]

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26 S. E. CALIFORNIA and S. W. ARIZONA—Physical Environment and Agriculture of the Desert Regions . . . . .

27 THAILAND—Physical Environment and Agriculture

28 BURMA—Physical Environment and Agriculture

28A BURMA—Diseases and Pests of Economic Plants

28B BURMA—Climate, Soils and Rice Culture (Supplementary Information and a Bibliography to Report 28)

29A VIETNAM, CAMBODIA, LAOS—Physical Environment and Agriculture . . . .

29B VIETNAM, CAMBODIA, LAOS—Diseases and Pests of Economic Plants . . . .

29C VIETNAM, CAMBODIA, LAOS—Climatological Data (Supplement to Report 29A)

30A CENTRAL and SOUTH CHINA, HONG KONG, TAIWAN—Physical Environment and Agriculture $20.00*

30B CENTRAL and SOUTH CHINA, HONG KONG, TAIWAN—Major Plant Pests and Diseases . . . . . .

31 SOUTH CHINA—Its Agro-Climatic Analogues in Southeast Asia

32 SACRAMENTO-SAN JOAQUIN DELTA OF CALIFORNIA—Physical Environment and Agriculture . . . . .

33 GLOBAL AGROCLIMATIC ANALOGUES FOR THE RICE REGIONS OF THE CONTINENTAL UNITED STATE

34 AGRO-CLIMATOLOGY AND GLOBAL AGROCLIMATIC ANALOGUES OF THE CITRUS REGIONS OF THE CONTINENTAL UNITED STATES

35 GLOBAL AGROCLIMATIC ANALOGUES FOR THE SOUTHEASTERN ATLANTIC REGION OF THE CONTINENTAL UNITED STATES

36 GLOBAL AGROCLIMATIC ANALOGUES FOR THE INTERMOUNTAIN REGION OF THE CONTINENTAL UNITED STATES

37 GLOBAL AGROCLIMATIC ANALOGUES FOR THE NORTHERN GREAT PLAINS REGION OF THE CONTINENTAL UNITED STATES

38 GLOBAL AGROCLIMATIC ANALOGUES FOR THE MAYAGUEZ DISTRICT OF PUERTO RICO

39 RICE CULTURE and RICE-CLIMATE RELATIONSHIPS With Special Reference to the United States Rice Areas and Their Latitudinal and Thermal Analogues in Other Countries

40 E. WASHINGTON, IDAHO, and UTAH—Physical Environment and Agriculture

41 WASHINGTON, IDAHO, and UTAH—The Use of Phenology in Ascertaining the Temperature Requirements of Wheat Grown in Washington, Idaho, and Utah and in Some of Their Agro-Climatically Analogous Areas in the Eastern Hemisphere

42 NORTHERN GREAT PLAINS REGION—Preliminary Study of Phenological Temperature Requirements of a Few Varieties of Wheat Grown in the Northern Great Plains Region and in Some Agro-Climatically Analogous Areas in the Eastern Hemisphere

43 SOUTHEASTERN ATLANTIC REGION—Phenological Temperature Requirements of Some Winter Wheat Varieties Grown in the Southeastern Atlantic Region of the United States and in Several of Its Latitudinally Analogous Areas of the Eastern and Southern Hemispheres of Seasonally Similar Thermal Conditions

44 ATMOSPHERIC AND METEOROLOGICAL ASPECTS OF AIR POLLUTION—A Survey of USSR Air Pollution Literature

45 EFFECTS AND SYMPTOMS OF AIR POLLUTES ON VEGETATION; RESISTANCE AND SUSCEPTIBILITY OF DIFFERENT PLANT SPECIES IN VARIOUS HABITATS, IN RELATION TO PLANT UTILIZATION FOR SHELTER BELTS AND AS BIOLOGICAL INDICATORS—A Survey of USSR Air Pollution Literature

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1971

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TABLE OF CONTENTS

Page

PREFACE v

Maps of the USSR

Orientation vii
Climatic, Soil and Vegetation Zones viii
Major Economic Areas ix
Major Industrial Centers x
Principal Centers of Ferrous Metallurgy and Main Iron Ore Deposits xi
Principal Centers of Non-Ferrous Metallurgy and Distribution of Most Important Deposits of Non-Ferrous Metal Ores xii
Principal Centers of the Chemical Industry and of the Textile Industry xiii
Principal Centers of Wood-Working, Paper, and Food Industries xiv
Main Mining Centers xv
Principal Electric Power Stations and Power Systems xvi

DISTRIBUTION OF AEROSOLS IN THE FREE ATMOSPHERE AROUND KRASNOYARSK
M. A. Belyashova 1

SPECTRAL METHOD OF DETERMINATION OF A SERIES OF ELEMENTS IN ATMOSPHERIC AEROSOLS
N. N. Aleksandrov, N. A. Panichev, M. A. Rzhaksinskaya, and Yu. I. Turkin 12

SANITARY EVALUATION OF AIR POLLUTION IN AREAS AROUND FERROUS METALLURGICAL PLANTS
Ye. V. Yelfimova, N. S. Yevseyenko, Ya. K. Yushko, N. N. Pushkina, S. K. Nenasheva, and G. N. Kuznetsova 22

SANITARY EVALUATION OF AIR POLLUTION AROUND FERROUS METALLURGICAL PLANTS
A. P. Makhinya 27

EXPERIMENT IN THE USE OF A HELICOPTER FOR A HYGIENIC STUDY OF THE DYNAMICS OF AIR POLLUTION
R. S. Gil'denskiol'd, B. V. Rikhter, and V. M. Styazhkin 32

Page

NEW METHOD OF CALCULATING THE DISPERSAL OF DISCHARGES FROM THERMAL ELECTRIC POWER PLANTS IN ATMOSPHERIC AIR AND ITS SANITARY EVALUATION
R. S. Gil'denskiol'd, B. V. Rikhter, and V. M. Styazhkin 35

SANITARY EVALUATION OF ATMOSPHERIC AIR POLLUTION IN THE AREA OF A HIGH CAPACITY THERMAL ELECTRIC POWER PLANT
R. S. Gil'denskiol'd, B. V. Rikhter, and V. M. Styazhkin 42

DISCHARGE OF FLUE GASES AND ASH BY ELECTRIC POWER PLANTS AND CALCULATION OF THEIR CONCENTRATIONS IN THE ATMOSPHERE
B. S. Belosl'skiy 49
Introduction 50
1. Dispersal of Discharges from Smokestacks and Calculation of Concentrations of Fly Ash and Gases in the Atmosphere 51
2. Particle Size Composition of the Carryover and Evaluation of the Efficiency of Operation of Ash Collectors 67
3. Calculation of Smokestack Parameters and Evaluation of the Maximum Output of Electric Power Plants 74
Appendix I 79
Appendix II 81
Appendix III 84
Appendix IV 90
Literature Cited 93

PREFACE

Much of the background material presented in the prefaces to the preceding volumes of this series is also relevant to the present volume.

The papers and data presented in this volume deal with a number of aspects of air pollution developed under the wide range of environmental conditions prevailing throughout the vast land area of the USSR with its numerous extractive and manufacturing industrial enterprises. Some background information on the distribution of the Soviet industry's production machine may be of interest in connection with that country's present and potential pollution problems and investigations. The planned distribution of production in the Soviet Union favors effective exploitation of the natural resources of the USSR, especially in its eastern areas where enormous natural resources are concentrated, and has led to the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas (see page ix). The many diverse climatic conditions of the country and its major economic areas as well as the geographical distribution of the Soviet Union's principal industrial and mining centers and of its principal electric power stations and power systems can be seen from the various maps presented as background material in this volume.

Contamination of the natural environment constitutes a major problem in all industrial regions of the USSR. The country's industry and transport are continually bringing about massive qualitative changes in the habitat of man and vegetation through an ever-increasing pollution of air, soil, and streams. Pollution and the need to control it have become a matter of great concern among Soviet conservationists and scientists and they, like their colleagues in the West, have been warning their government of the colossal and sometimes irreparable damage that is being done to the environment and urging that serious and effective steps be taken to avert it.

Public awareness of the environmental crisis and the pollution problem has been greatly stimulated in the USSR by the description, in the local press, of such phenomena as dirty urban air, polluted rivers, ravaged forests and public parks, and poisoned wildlife as well as by the revealing of the causes of these conditions. "Pravda", the official Communist party newspaper, stated in a recent article that "... we are turning the atmosphere of our major industrial regions and large cities into a dump for poisonous industrial wastes". In the Soviet Union, like in the West, pollution now poses for the leaders of the country some fundamental choices between the economics of production, on one hand, and the progressively worsening living conditions, on the other. There appears to be, at present, a greater appreciation and a better understanding of the immense problems of air and water pollution on the part of the urban and rural administrative agencies. As a result of a mounting demand for the maintenance of a high quality physical environment, protective measures against the pollution threat are gradually taking shape in the USSR and much relevant air pollution research data are being developed in the various industrial regions of that country.

Studies of atmospheric diffusion and air pollution constitute a rapidly developing area of meteorological sciences in the USSR. Determination and analysis of the complex set of meteorological factors causing the processes of atmospheric diffusion are being extensively developed there in conjunction with theoretical and experimental studies of the pattern of propagation and distribution of contaminants in the atmosphere.

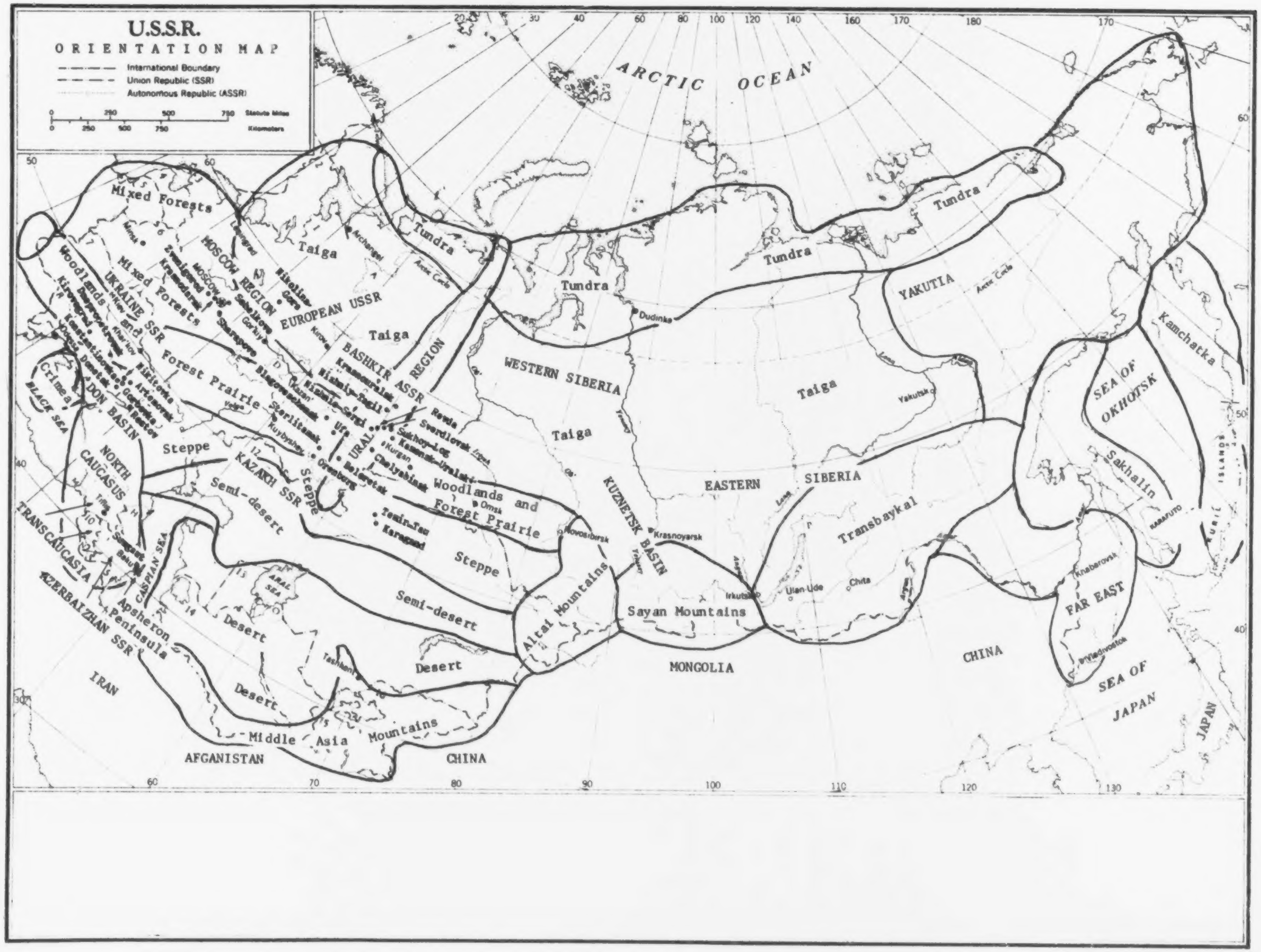
Most of the material brought together in this volume deals with atmospheric air pollution caused by electric power plants and with the calculation of the concentrations and the sanitary evaluation of flue gases and ash fly discharged by these plants.

A number of papers presented here deal with sanitary evaluations of air pollution around ferrous metallurgical plants. Other papers consist of reports relating to the distribution of aerosols in a free atmosphere and a description of some methods for determination of a series of elements in the atmospheric aerosols.

It is hoped that the papers selected for presentation in this volume will be conducive to a better appreciation of some of the air pollution investigations conducted in the USSR. As the editor of this volume I wish to thank my co-workers in the Air Pollution Section of the Institute for their valuable assistance.

M. Y. Nuttonson

May 1971


U.S.S.R.
ORIENTATION MAP
International Boundary
Union Republic (SSR)
Autonomous Republic (ASSR)
0 250 500 750 Statute Miles
0 250 500 750 Kilometers
ARCTIC OCEAN
Mixed Forests
Taiga
Tundra
MOSCOW REGION
Moscow
Zvenigorod
Krasnodarsk
Sablikovo
Sharapovo
Gor'kiy
Nikolina Gora
Leningrad
Archangel
Arctic Circle
Minsk
EUROPEAN USSR
Kirov
UKRAINE SSR
Woodlands and Mixed Forests
Kiev
Khar'kov
Dnepropetrovsk
Kirovograd
Konstantinovka
Donetsk
Artemovsk
Nikitovka
Gorlovka
Rostov
DON BASIN
Crimea
BLACK SEA
Forest Prairie
Volga
Kazan'
Blagoveshchensk
Sterlitamak
Kuybyshev
BASHKIR ASSR
Krasnouralsk
Nizhniy Tagil
Nizhniye Sergi
Ufa
URAL REGION
Revda
Sverdlovsk
Sukhoy Log
Kamensk-Ural'skiy
Kurgan
Chelyabinsk
Beloretsk
Orenburg
Steppe
KAZAKH SSR
Semi-desert
Temir-Tau
Karaganda
Woodlands and Forest Prairie
Omsk
NORTH CAUCASUS
TRANSCAUCASIA
Tbilisi
Sumgait
Baku
CASPIAN SEA
AZERBAIZHAN SSR
Apsheron Peninsula
ARAL SEA
Desert
Tashkent
Middle Asia Mountains
IRAN
AFGANISTAN
CHINA
WESTERN SIBERIA
Dudinka
Novosibirsk
KUZNETSK BASIN
Krasnoyarsk
Altai Mountains
Sayan Mountains
MONGOLIA
EASTERN SIBERIA
Irkutsk
Ulan-Ude
Chita
Transbaykal
Lena
Yakutsk
YAKUTIA
Kamchatka
SEA OF OKHOTSK
Sakhalin
KARAFUTO
KURIL ISLANDS
Khabarovsk
FAR EAST
Vladivostok
SEA OF JAPAN
JAPAN
20 30 40 60 80 100 120 140 160 170 180 170
50 60 40 30
60 70 80 90 100 110 120 130
1 2 3 4 5 6 7 10 12 13 14 15 A D E H J K

ADMINISTRATIVE DIVISIONS

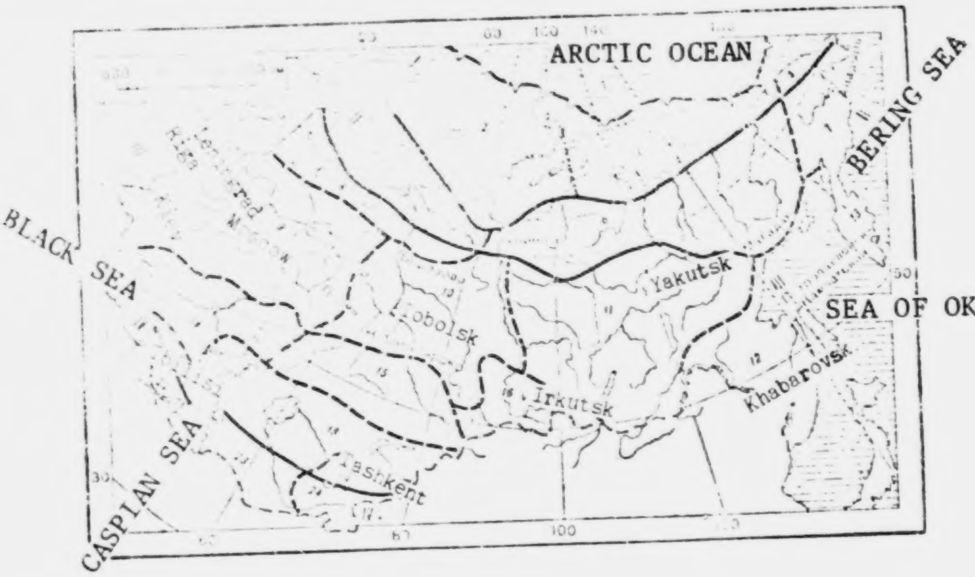
S.S.R.

1. R.S.F.S.R
2. Karelo-Finnish S.S.R
3. Estonian S.S.R
4. Latvian S.S.R.
5. Lithuanian S.S.R.
6. White Russian S.S.R.
7. Ukrainian S.S.R
8. Moldavian S.S.R.
9. Georgian S.S.R.
10. Armenian S.S.R.
11. Azerbaydzhan S.S.R
12. Kazakh S.S.R.
13. Uzbek S.S.R.
14. Turkmen S.S.R
15. Tadzhik S.S.R.
16. Kirgiz S.S.R.

A.S.S.R.

A. Komi ASSR
B. Udmurtskaya ASSR
C. Mariyskaya ASSR
D. Chuvashskaya ASSR
E. Mordovskaya ASSR
F. Tatarskaya ASSR
G. Bashkirskaya ASSR
H. Dagestanskaya ASSR
J. Severo-Osetinskaya ASSR
K. Kabardinskaya ASSR
L. Abkhazskaya ASSR
M. Adzharskaya ASSR
N. Nakhichevanskaya ASSR
O. Kara-Kalpakskaya ASSR
P. Buryat-Mongol'skaya ASSR
Q. Yakutskaya ASSR

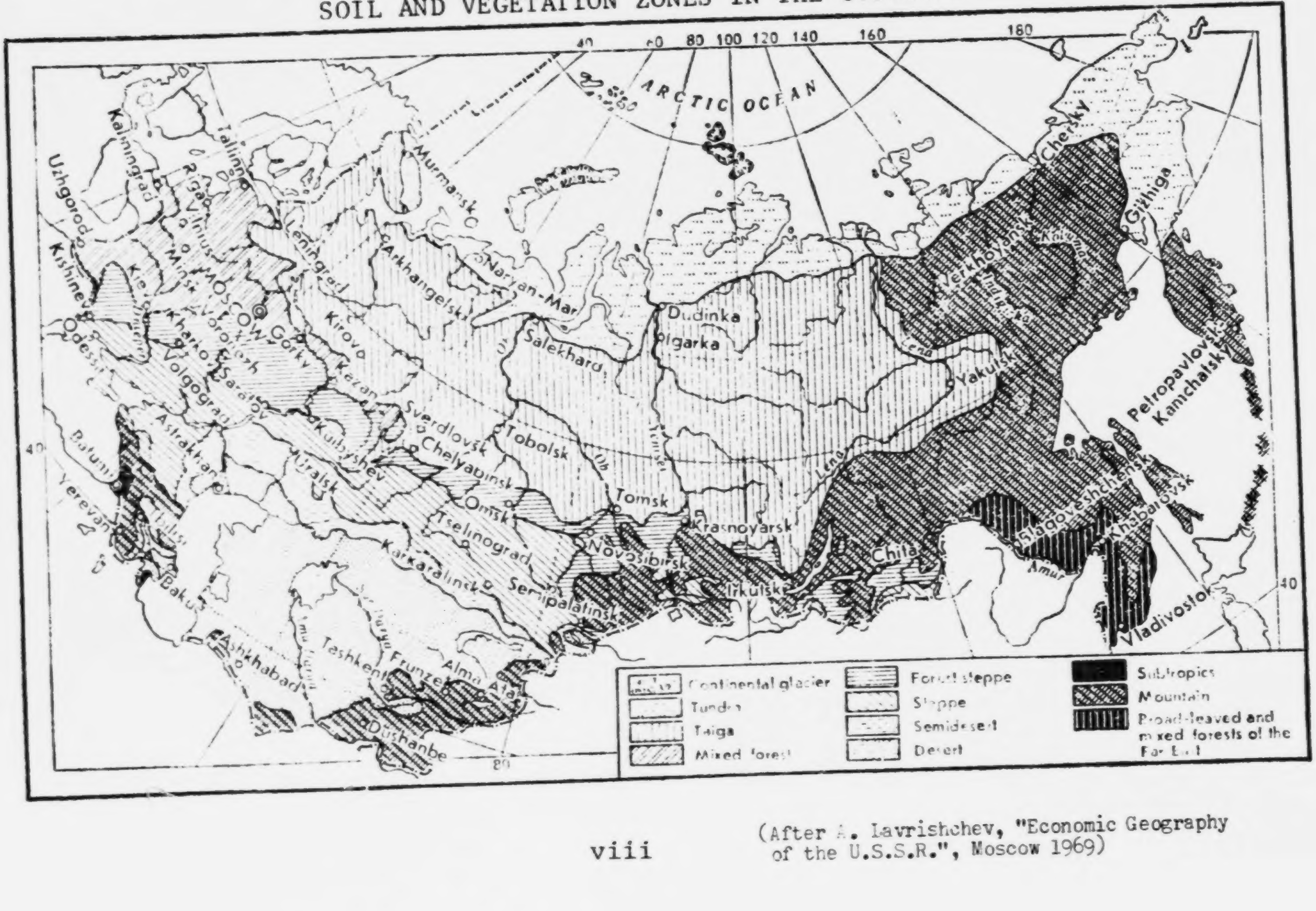
CLIMATIC ZONES AND REGIONS* OF THE USSR


ARCTIC OCEAN
BERING SEA
BLACK SEA
SEA OF OKHOTSK
CASPIAN SEA
Leningrad
Moscow
Yakutsk
Tobolsk
Irkutsk
Khabarovsk
Tashkent
100

Zones: I-arctic, II-subarctic, III-temperate, IV-subtropical
Regions: 1-polar, 2-Atlantic, 3-East Siberian, 4-Pacific, 5-Atlantic, 6-Siberian, 7-Pacific, 8-Atlantic-arctic, 9-Atlantic-continental forests, 10-continental forests West Siberian, 11-continental forests East Siberian, 12-monsoon forests, 13-Pacific forests, 14-Atlantic-continental steppe, 15-continental steppe West Siberian, 16-mountainous Altay and Sayan, 17-mountainous Northern Caucasus, 18-continental desert Central Asian, 19-mountainous Tyan-Shan, 20-western Transcaucasian, 21-eastern Transcaucasian, 22-mountainous Transcaucasian highlands, 23-desert south-Turanian, 24-mountainous Pamir-Alay

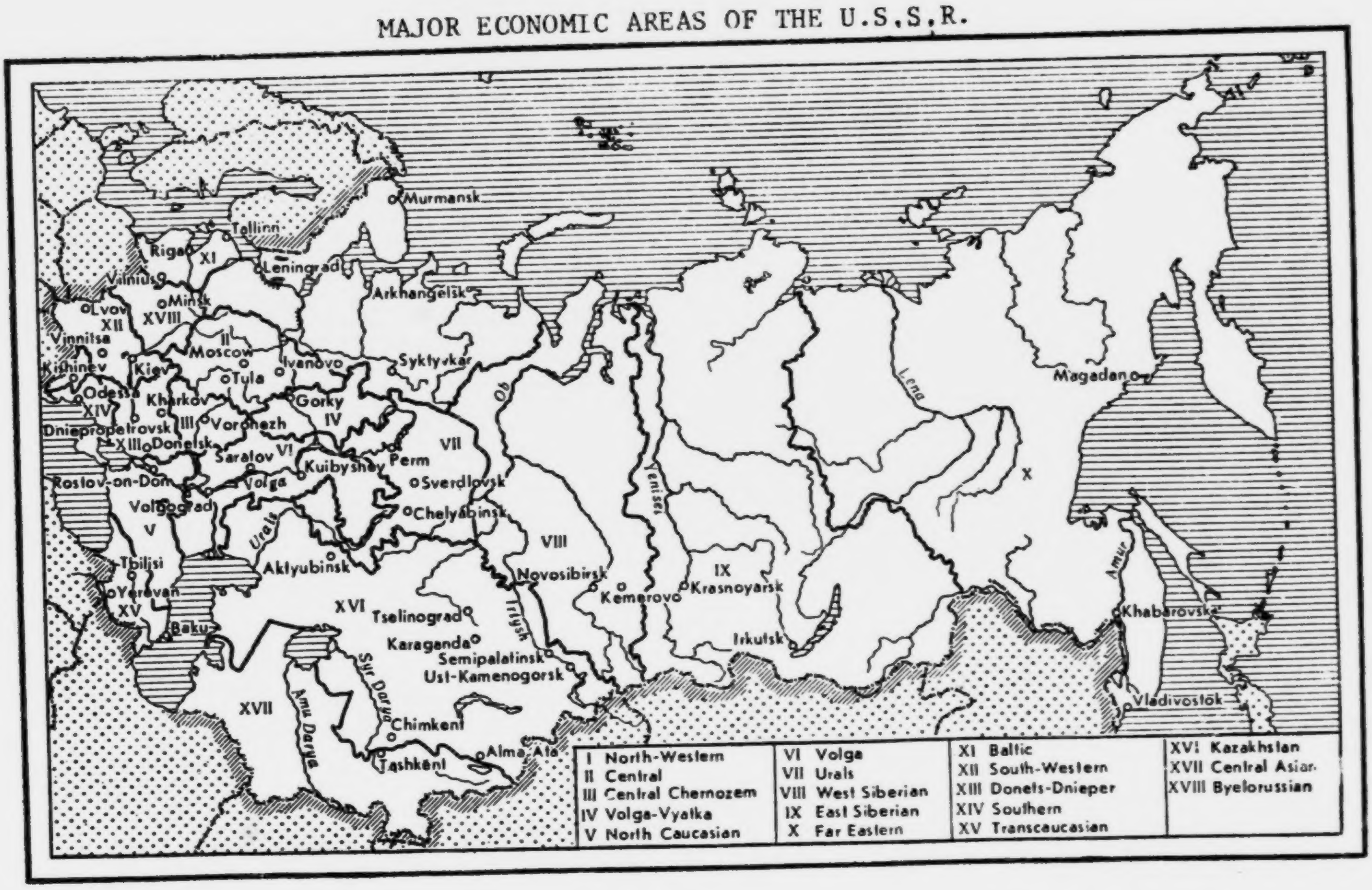
(After B. P. Alisov, "Climate of The USSR", Moscow 1956)

SOIL AND VEGETATION ZONES IN THE U.S.S.R.


ARCTIC OCEAN
40
60 80 100 120 140
160
180
Murmansk
Tallinn
Riga
Vilnius
Kaliningrad
Uzhgorod
Kishinev
Odessa
Kiev
Minsk
Leningrad
Moscow
Kharkov
Voronezh
Gorky
Volgograd
Saratov
Kirov
Kazan
Arkhangelsk
Naryan-Mar
Salekhard
Dudinka
Igarka
Sverdlovsk
Chelyabinsk
Kuibyshev
Astrakhan
Uralsk
Tobolsk
Omsk
Tselinograd
Karaganda
Semipalatinsk
Tomsk
Novosibirsk
Krasnoyarsk
Irkutsk
Chita
Yakutsk
Verkhoyansk
Chersky
Gizhiga
Petropavlovsk-Kamchatsky
Blagoveshchensk
Khabarovsk
Vladivostok
Amur
Batumi
Yerevan
Tbilisi
Baku
Ashkhabad
Tashkent
Frunze
Alma-Ata
Dushanbe
Continental glacier
Tundra
Taiga
Mixed forest
Forest steppe
Steppe
Semidesert
Desert
Subtropics
Mountain
Broad-leaved and mixed forests of the Far East

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

MAJOR ECONOMIC AREAS OF THE U.S.S.R.


Murmansk
Tallinn
Riga
XI
Leningrad
Arkhangelsk
Vilnius
Minsk
Lvov
XVIII
XII
Vinnitsa
Kishinev
Kiev
Moscow
II
Ivanovo
Syktyvkar
Odessa
Kharkov
Tula
Gorky
IV
XIV
III
Voronezh
Dniepropetrovsk
XIII
Donetsk
Saratov
VI
Kuibyshev
Perm
VII
Rostov-on-Don
Volga
Sverdlovsk
Volgograd
Chelyabinsk
V
Urals
Tbilisi
Aktyubinsk
VIII
Yerevan
XV
Baku
XVI
Tselinograd
Novosibirsk
Kemerovo
IX
Krasnoyarsk
Karaganda
Semipalatinsk
Ust-Kamenogorsk
Irtysh
Ob
Yenisei
Lena
Irkutsk
Magadan
X
Amur
Khabarovsk
Vladivostok
XVII
Amu Darya
Syr Darya
Chimkent
Tashkent
Alma-Ata
I North-Western
II Central
III Central Chernozem
IV Volga-Vyatka
V North Caucasian
VI Volga
VII Urals
VIII West Siberian
IX East Siberian
X Far Eastern
XI Baltic
XII South-Western
XIII Donets-Dnieper
XIV Southern
XV Transcaucasian
XVI Kazakhstan
XVII Central Asian
XVIII Byelorussian

PLANNED DISTRIBUTION OF INDUSTRIAL PRODUCTION IN ORDER TO BRING IT CLOSER TO RAW MATERIAL AND FUEL SOURCES

An example of the planned distribution of industrial production in the USSR is the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas: the North-West (Kirovsk, Kandalaksha, Vorkuta), the Urals (Magnitogorsk, Chelyabinsk, Nizhny Tagil), Western and Eastern Siberia (Novosibirsk, Novokuznetsk, Kemerovo, Krasnoyarsk, Irkutsk, Bratsk), Kazakhstan (Karaganda, Rudny, Balkhash, Dzhezkazgan).

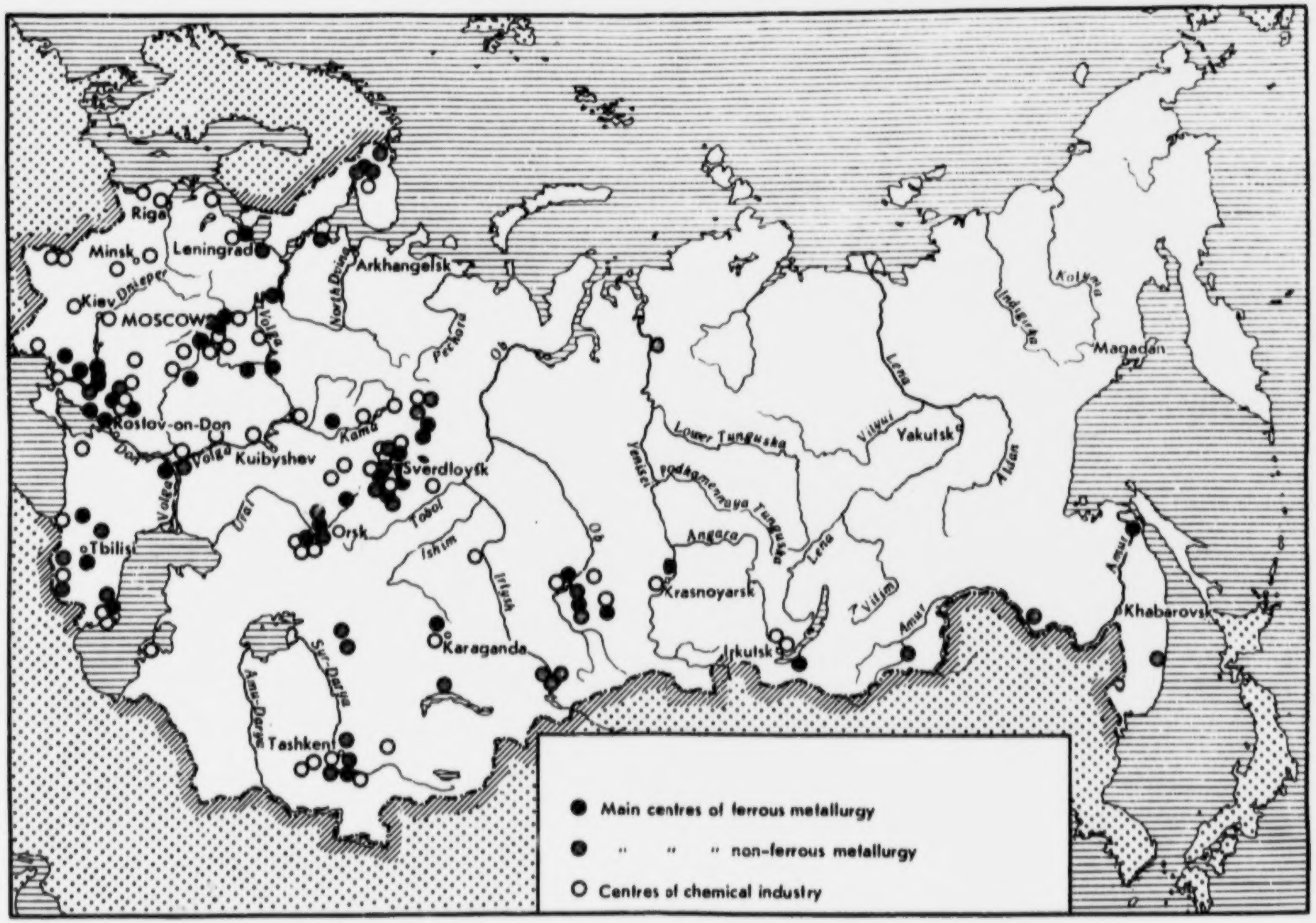
Large industrial systems are being created - Kustanai, Pavlodar-Ekibastuz, Achinsk-Krasnoyarsk, Bratsk-Taisnet and a number of others. Ferrous and non-ferrous metallurgy, pulp and paper, hydrolysis and saw-milling industries are being established in the Bratsk-Taishet industrial system. The Achinsk-Krasnoyarsk industrial system is becoming one of the largest centers of aluminum and chemical industries, and production of ferrous metals, cellulose, paper, and oil products.

Construction of the third metallurgical base has been launched in Siberia, and a new base of ferrous metallurgy, using the enormous local iron and coal resources, has been created in Kazakhstan. A high-capacity power system is being organized in the same areas. Non-ferrous metallurgy is being further developed in Kazakhstan, Central Asia and in Transbaikal areas. The pulp and paper, as well as the timber, industries are being developed at a fast rate in the forest areas of Siberia and the Far East.

Ferrous metallurgy is also developing in the European part of the country by utilizing the enormous iron ore resources of the Kursk Magnetic Anomaly and the Ukrainian deposits. Large new production systems are under construction in the North-West, along the Volga, in the Northern Caucasus and the Ukraine.

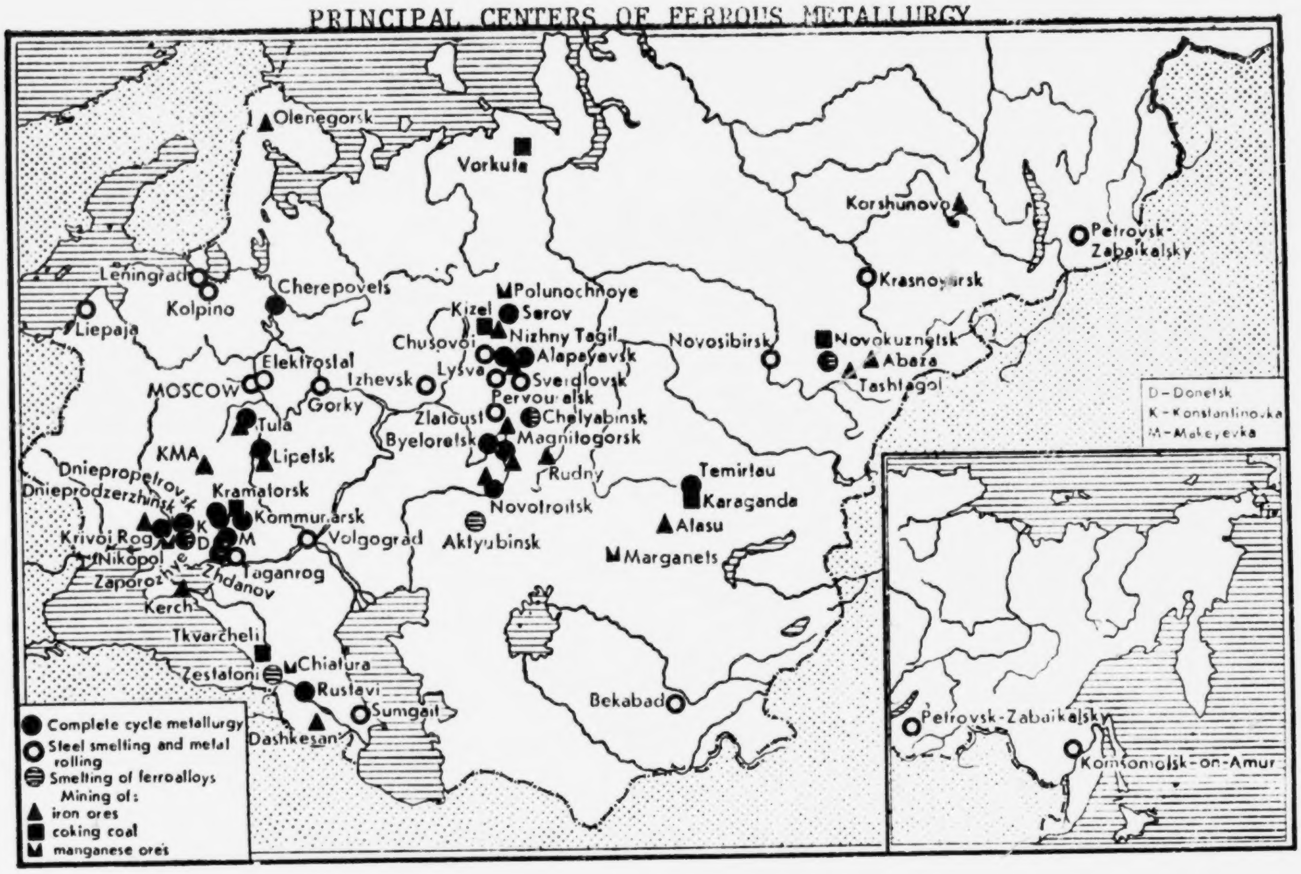
(After A. Lavrishchev, "Economic Geography
of the U.S.S.R.", Moscow 1969)

THE MAJOR INDUSTRIAL CENTERS OF THE USSR

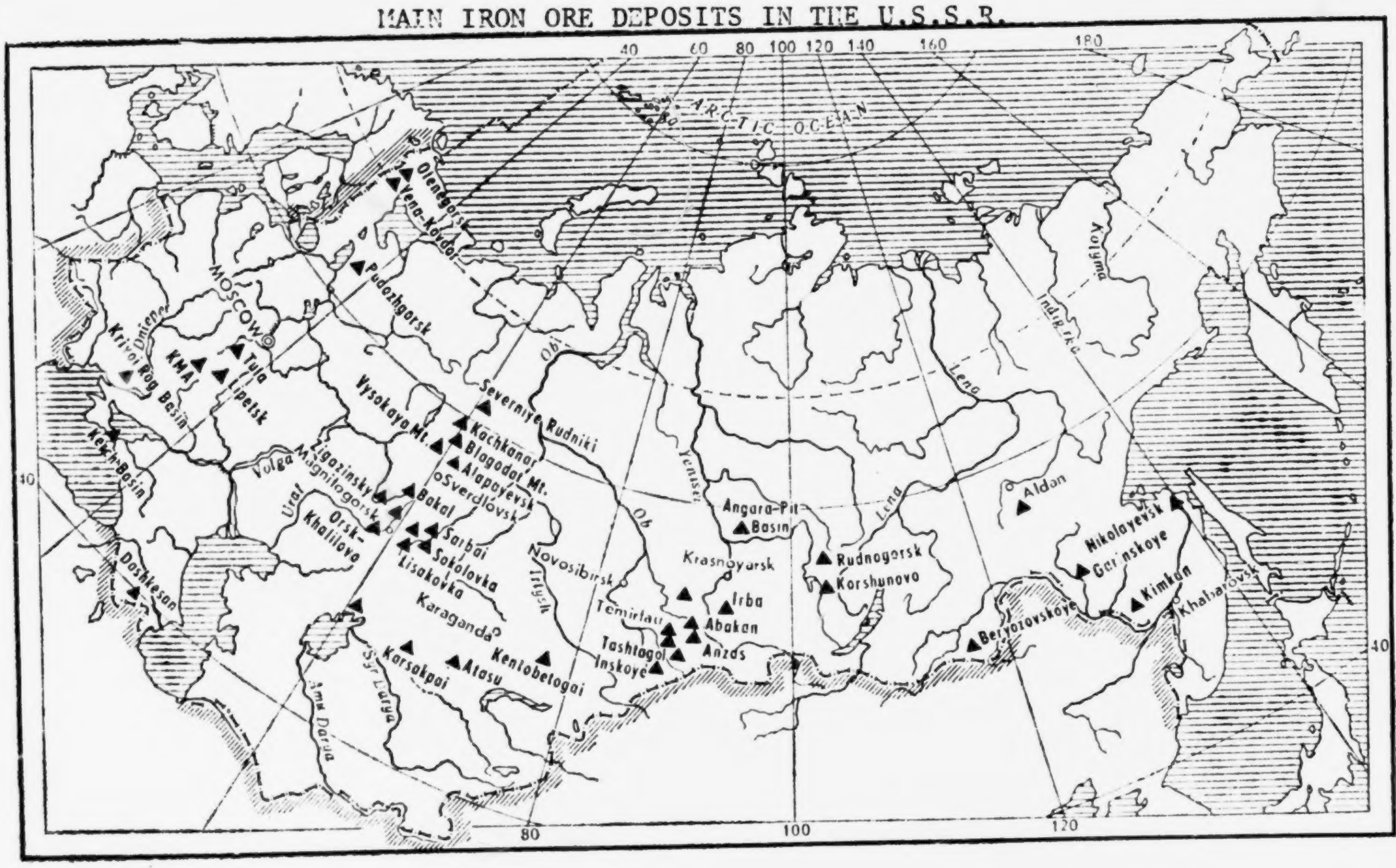

Riga
Minsk
Leningrad
Arkhangelsk
Kiev
Dnieper
MOSCOW
Volga
North Dvina
Pechora
Ob
Kama
Rostov-on-Don
Don
Volga
Kuibyshev
Sverdlovsk
Ural
Orsk
Tobol
Ishim
Irtysh
Tbilisi
Karaganda
Syr-Darya
Amu-Darya
Tashkent
Ob
Yenisei
Lower Tunguska
Podkamennaya Tunguska
Angara
Krasnoyarsk
Irkutsk
Lena
Vilyui
Yakutsk
Aldan
Vitim
Amur
Indigirka
Kolyma
Magadan
Khabarovsk
● Main centres of ferrous metallurgy
● " " " non-ferrous metallurgy
○ Centres of chemical industry

(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL CENTERS OF FERROUS METALLURGY

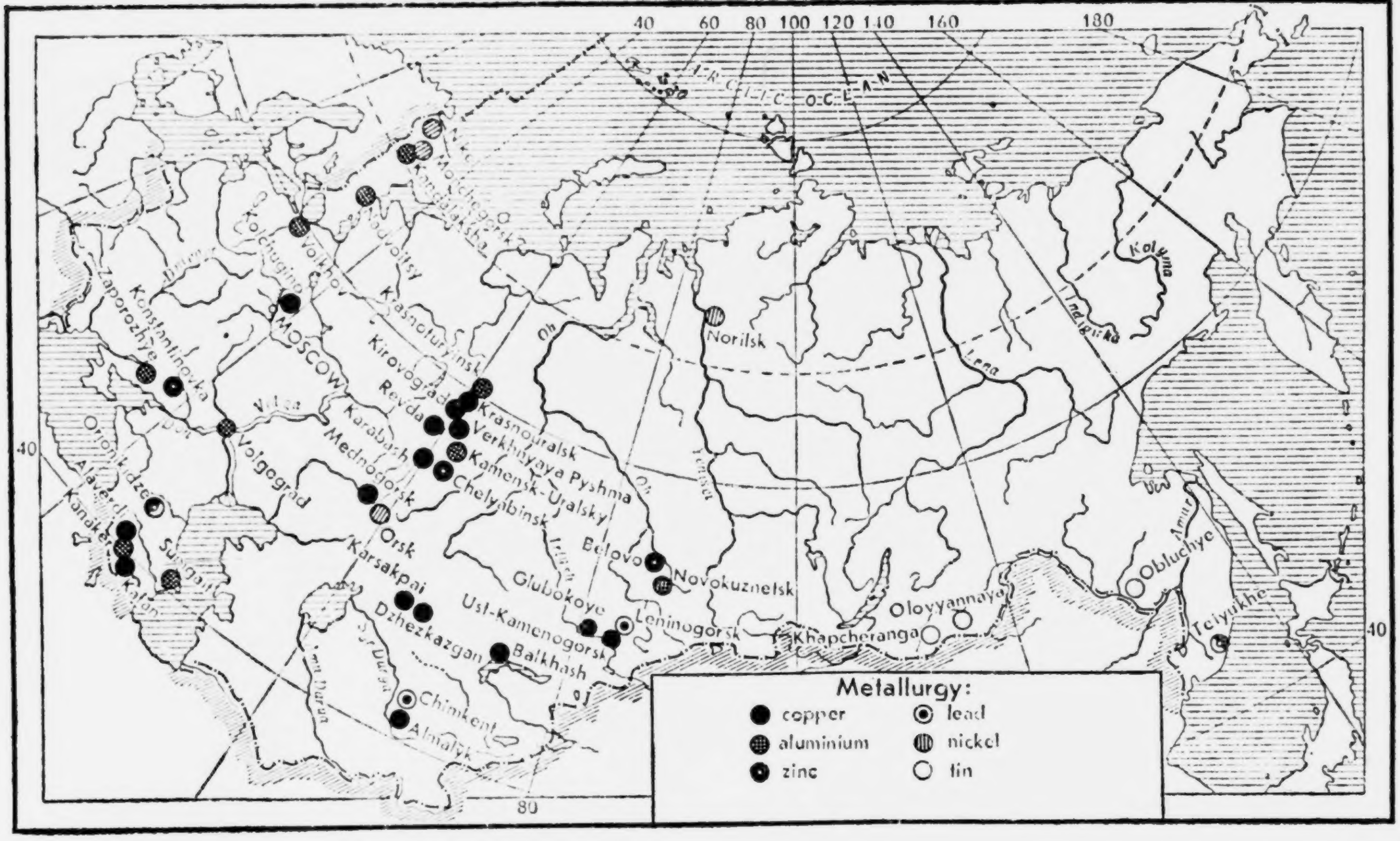

Olenegorsk
Vorkuta
Korshunovo
Petrovsk-Zabaikalsky
Leningrad
Kolpino
Liepaja
Cherepovets
Polunochnoye
Kizel
Serov
Nizhny Tagil
Chusovoi
Alapayevsk
Lysva
Sverdlovsk
Pervouralsk
Krasnoyarsk
Novosibirsk
Novokuznetsk
Abaza
Tashtagol
Elektrostal
MOSCOW
Izhevsk
Gorky
Tula
Zlatoust
Chelyabinsk
Byeloretsk
Magnitogorsk
KMA
Lipetsk
Rudny
Dniepropetrovsk
Dnieprodzerzhinsk
Kramatorsk
Kommunarsk
Temirtau
Karaganda
Krivoi Rog
K
D
M
Volgograd
Novotroitsk
Aktyubinsk
Atasu
Nikopol
Zaporozhye
Zhdanov
Taganrog
Marganets
Kerch
Tkvarcheli
Chiatura
Zestafoni
Rustavi
Sumgait
Dashkesan
Bekabad
D – Donetsk
K – Konstantinovka
M – Makeyevka
Petrovsk-Zabaikalsky
Komsomolsk-on-Amur
● Complete cycle metallurgy
○ Steel smelting and metal rolling
⊜ Smelting of ferroalloys
Mining of:
▲ iron ores
■ coking coal
manganese ores

MAIN IRON ORE DEPOSITS IN THE U.S.S.R.

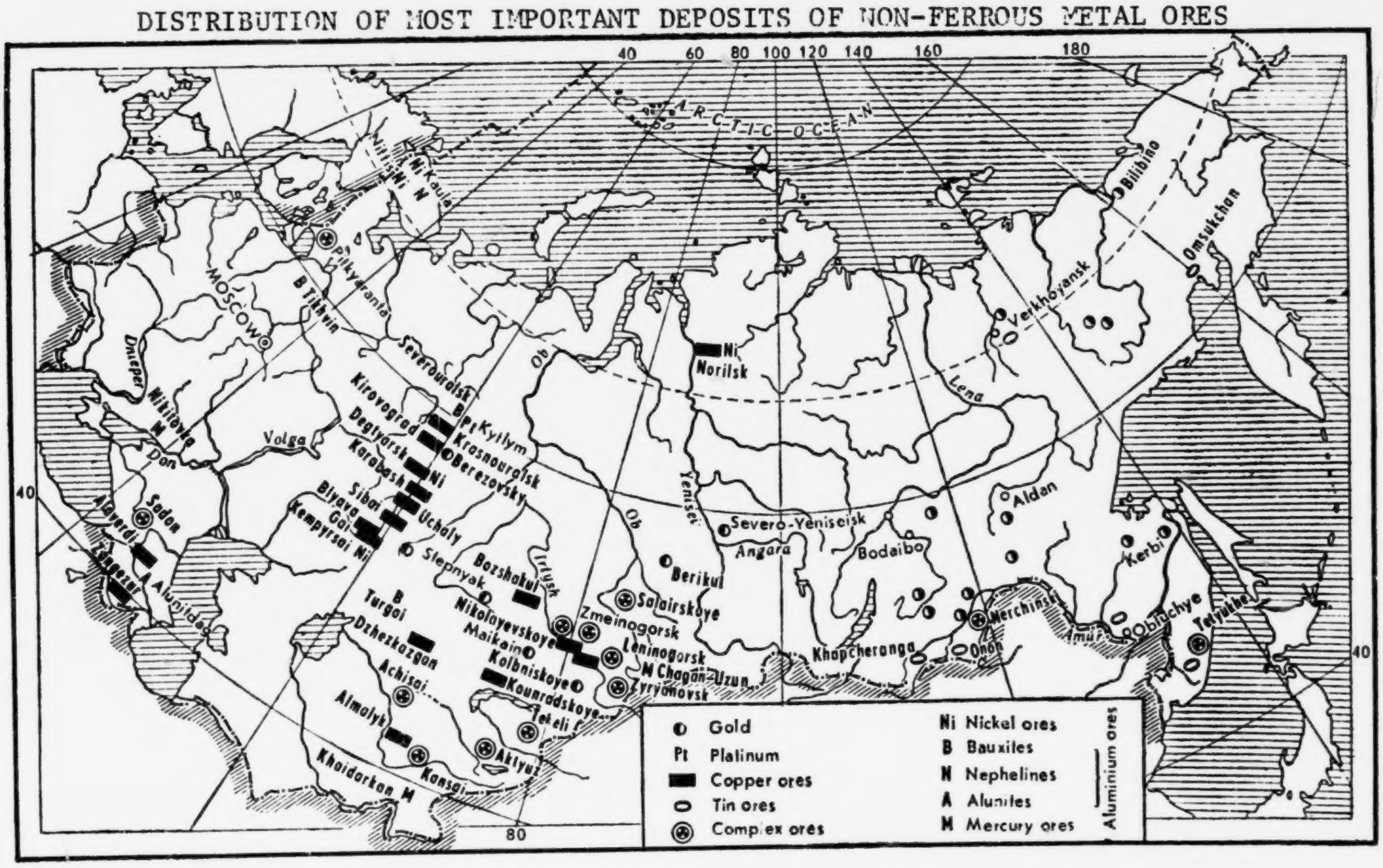

40
60
80
100
120
140
160
180
ARCTIC OCEAN
Olenegorsk
Yena-Kovdor
Pudozhgorsk
MOSCOW
Dnieper
Krivoi Rog Basin
KMA
Tula
Lipetsk
Kerch Basin
Dashkesan
Volga
Ural
Vysokaya Mt.
Kachkanar
Blagodat Mt.
Alapayevsk
Sverdlovsk
Severnye Rudniki
Zigazinsky
Magnitogorsk
Bakal
Orsk-Khalilovo
Sarbai
Sokolovka
Lisakovka
Karaganda
Karsakpai
Atasu
Kentobetogai
Syr Darya
Amu Darya
Ob
Irtysh
Novosibirsk
Yenisei
Krasnoyarsk
Temirtau
Tashtagol
Inskoye
Abakan
Anzas
Irba
Angara-Pit Basin
Rudnogorsk
Korshunovo
Lena
Aldan
Indigirka
Kolyma
Nikolayevsk
Gar'inskoye
Kimkan
Khabarovsk
Beryozovskoye
40
80
100
120

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF NON-FERROUS METALLURGY IN THE U.S.S.R.

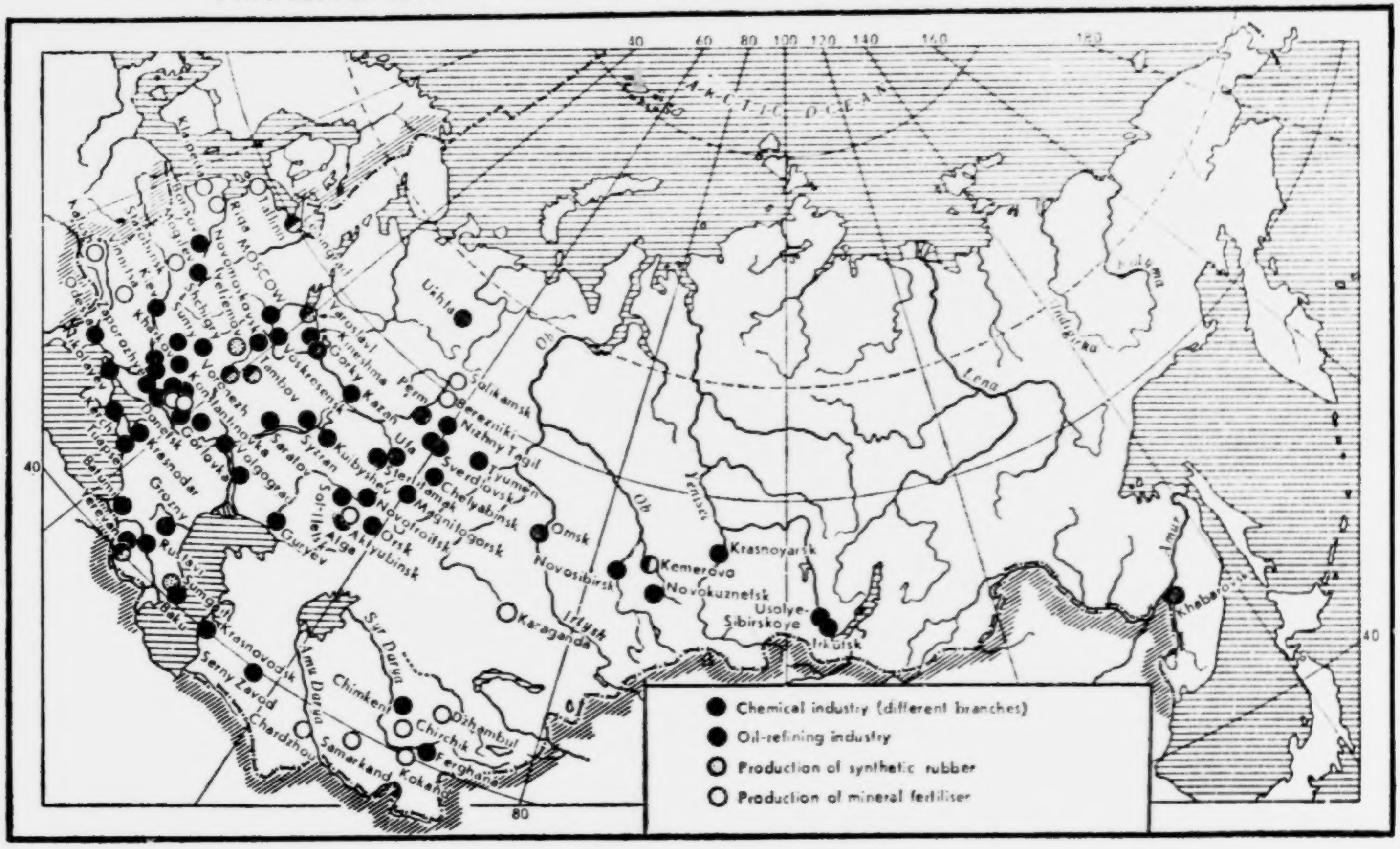

ARCTIC OCEAN
40
60
80
100
120
140
160
180
Monchegorsk
Kandalaksha
Volkhov
Boksitogorsk
Nadvoitsy
Krasnoturyinsk
Kirovograd
Revda
Krasnouralsk
Verkhnyaya Pyshma
Kamensk-Uralsky
Chelyabinsk
Karabash
Mednogorsk
Orsk
Karsakpai
Dzhezkazgan
Balkhash
Ust-Kamenogorsk
Glubokoye
Leninogorsk
Belovo
Novokuznetsk
Norilsk
Chimkent
Almalyk
Konstantinovka
Zaporozhye
Ordzhonikidze
Alaverdi
Kanaker
Sumgait
MOSCOW
Volgograd
Volga
Ob
Yenisei
Lena
Indigirka
Kolyma
Amur
Khapcheranga
Oloyyannaya
Obluchye
Tetyukhe
Metallurgy:
● copper
● aluminium
● zinc
⊙ lead
● nickel
○ tin

DISTRIBUTION OF MOST IMPORTANT DEPOSITS OF NON-FERROUS METAL ORES

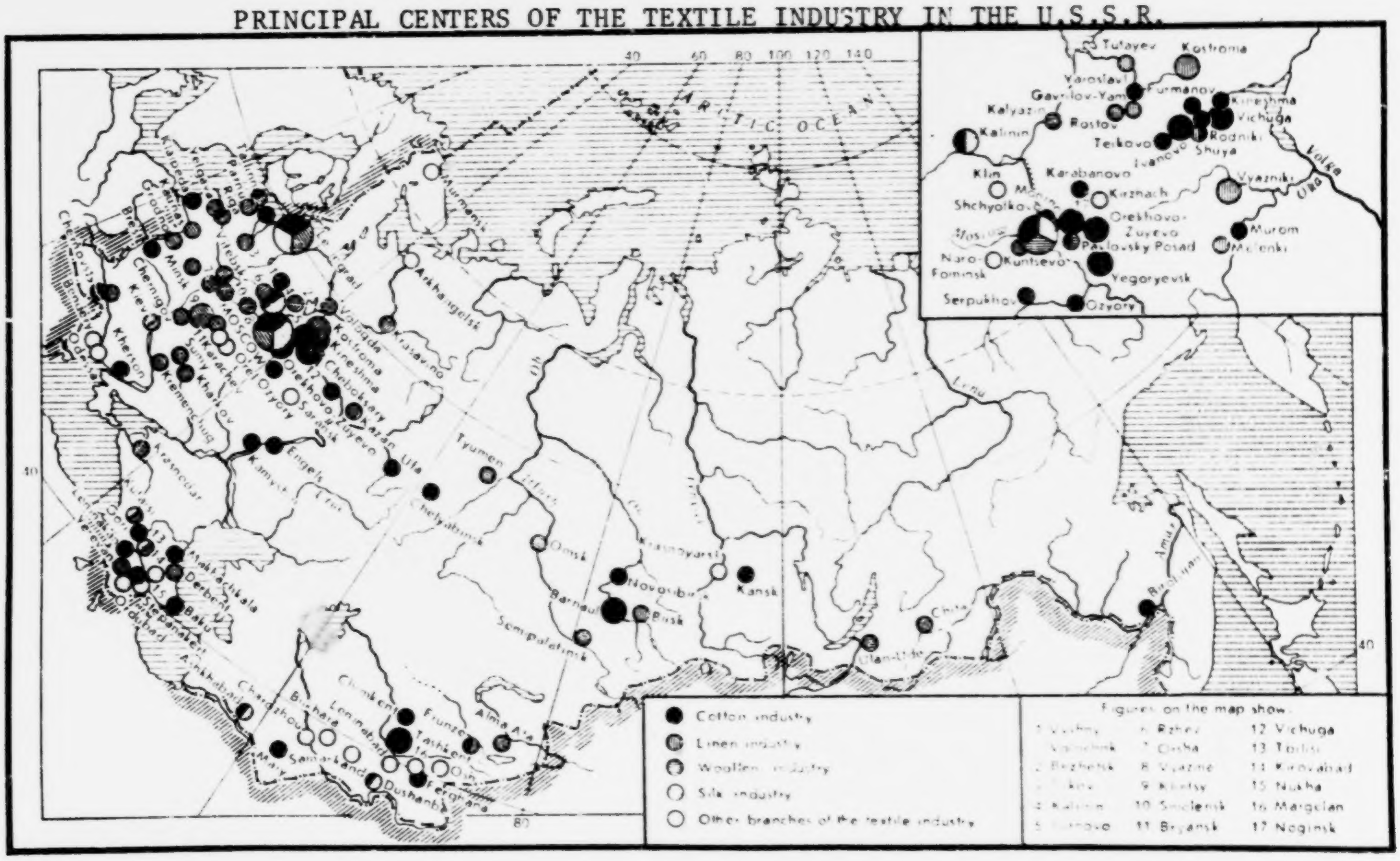

ARCTIC OCEAN
40
60
80
100
120
140
160
180
Ni Kaula
Pitkyaranta
B Tikhvin
MOSCOW
Dnieper
Nikitovka
Don
Volga
Severouralsk
Kirovograd
Kytlym
Krasnouralsk
Degtyarsk
Berezovsky
Karabash
Sibai
Uchaly
Blyava
Gai
Kempyrsai Ni
Stepnyak
Borshakul
Turgai
Dzhezkazgan
Nikolayevskoye
Maikain
Zmeinogorsk
Leninogorsk
Kolbinskoye
Kounradskoye
Chagan-Uzun
Zyryanovsk
Tekeli
Aktyuz
Achisai
Almalyk
Konsai
Khaidarkan
Sadon
Alaverdi
Kafan
Zaglik
Salairskoye
Berikul
Severo-Yeniseisk
Angara
Bodaibo
Nerchinsk
Onon
Khapcheranga
Aldan
Kerbi
Obluchye
Tetyukhe
Amur
Verkhoyansk
Bilibino
Omsukchan
Norilsk
Ob
Yenisei
Lena
Irtysh
Gold
Pt Platinum
Copper ores
Tin ores
Complex ores
Ni Nickel ores
B Bauxites
N Nephelines
A Alunites
M Mercury ores
Aluminium ores

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF THE CHEMICAL INDUSTRY IN THE U.S.S.R.

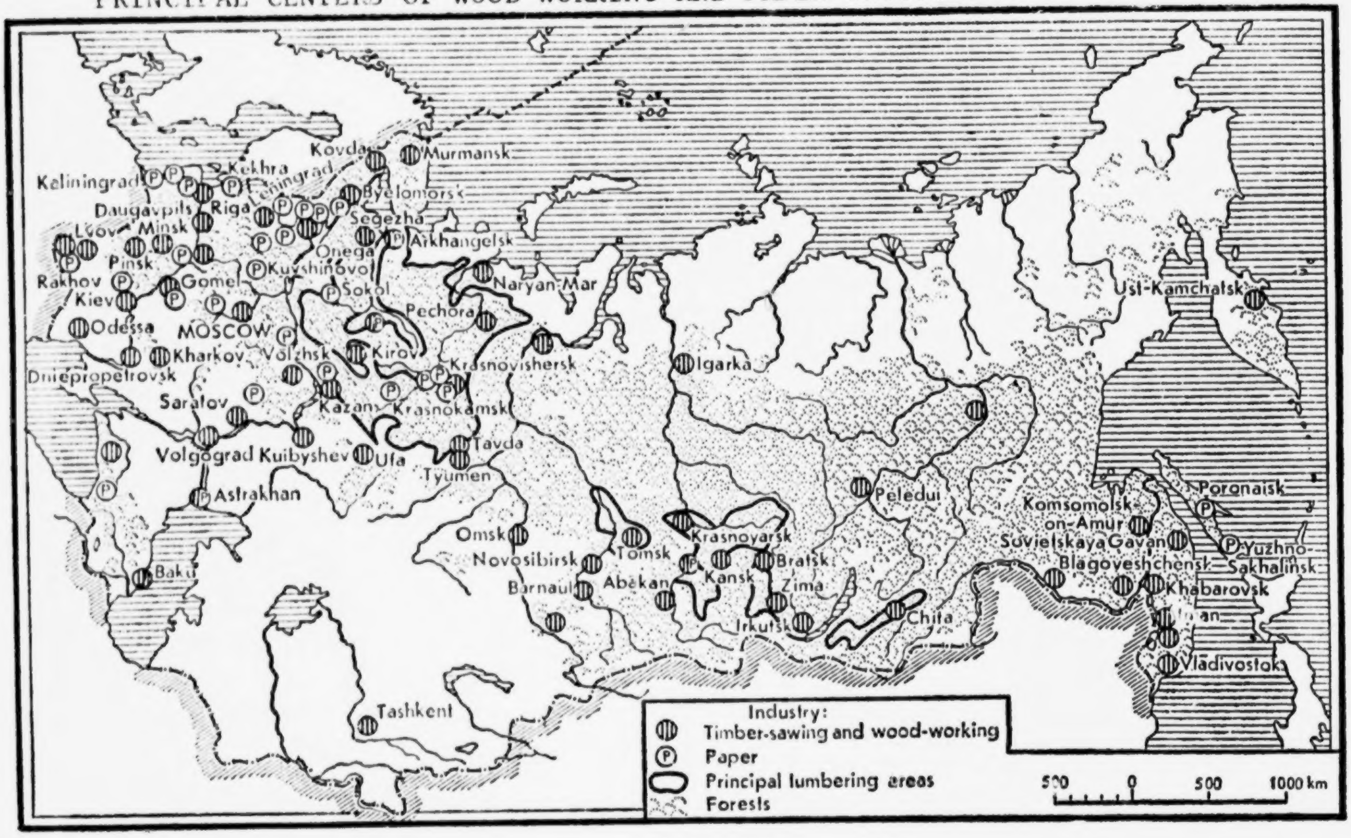

ARCTIC OCEAN
MOSCOW
Yaroslavl
Kineshma
Voskresensk
Gorky
Perm
Berezniki
Solikamsk
Nizhny Tagil
Sverdlovsk
Kazan
Ufa
Sterlitamak
Chelyabinsk
Tyumen
Kuibyshev
Syzran
Saratov
Volgograd
Voronezh
Tambov
Kharkov
Donetsk
Gorlovka
Krasnodar
Grozny
Rustavi
Sumgait
Baku
Guryev
Orsk
Novotroitsk
Aktyubinsk
Magnitogorsk
Omsk
Novosibirsk
Kemerovo
Novokuznetsk
Krasnoyarsk
Usolye-Sibirskoye
Irkutsk
Karaganda
Khabarovsk
Krasnovodsk
Serny Zavod
Chimkent
Chirchik
Dzhambul
Fergana
Kokand
Samarkand
Chardzhou
Ukhta
Lena
Ob
Yenisei
Irtysh
Amur
Syr Darya
Amu Darya
40
60
80
100
120
140
160
180
Chemical industry (different branches)
Oil-refining industry
Production of synthetic rubber
Production of mineral fertiliser

PRINCIPAL CENTERS OF THE TEXTILE INDUSTRY IN THE U.S.S.R.

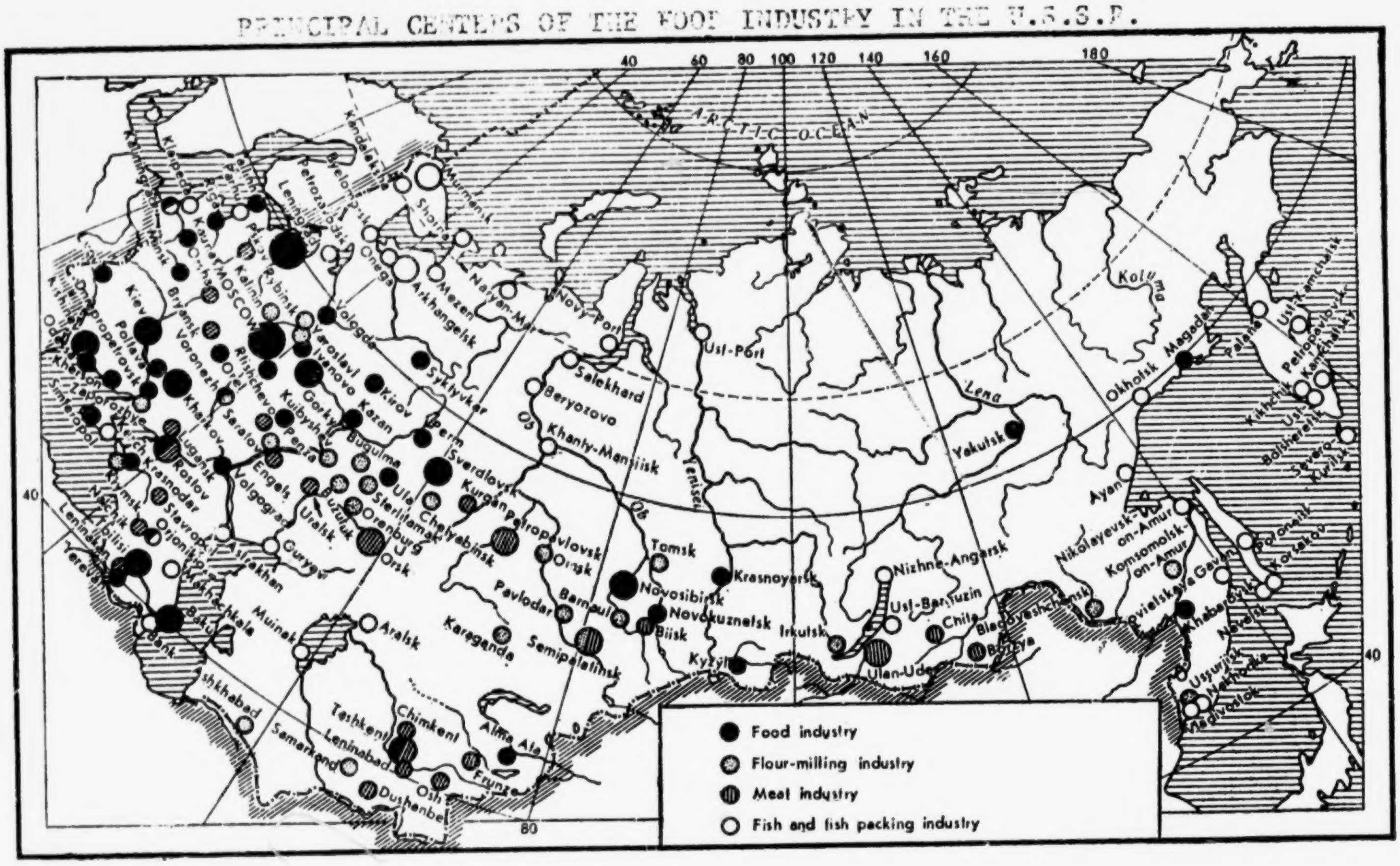

ARCTIC OCEAN
Tutayev
Kostroma
Yaroslavl
Gavrilov-Yam
Furmanov
Kalyazin
Rostov
Kineshma
Vichuga
Kalinin
Teikovo
Rodniki
Ivanovo
Shuya
Klin
Karabanovo
Kirzhach
Vyazniki
Shchyolkovo
Orekhovo-Zuyevo
Pavlovsky Posad
Murom
Melenki
Naro-Fominsk
Kuntsevo
Yegoryevsk
Serpukhov
Ozyory
Arkhangelsk
Kostroma
Cheboksary
Kazan
Ufa
Engels
Kamyshin
Chelyabinsk
Tyumen
Omsk
Novosibirsk
Barnaul
Biysk
Krasnoyarsk
Kansk
Semipalatinsk
Ulan-Ude
Chita
Kherson
Kiev
Minsk
Krasnodar
Makhachkala
Derbent
Baku
Ashkhabad
Chardzhou
Bukhara
Samarkand
Dushanbe
Tashkent
Frunze
Alma-Ata
Chimkent
Fergana
Cotton industry
Linen industry
Woollen industry
Silk industry
Other branches of the textile industry
Figures on the map show:
1 Vyshny Volochek
2 Bezhetsk
4 Kalinin
5 Ivanovo
6 Rzhev
7 Orsha
8 Vyazma
9 Klintsy
10 Smolensk
11 Bryansk
12 Vichuga
13 Tbilisi
14 Kirovabad
15 Nukha
16 Margelan
17 Noginsk
40
60
80
100
120
140

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF WOOD-WORKING AND PAPER INDUSTRIES IN THE U.S.S.R.

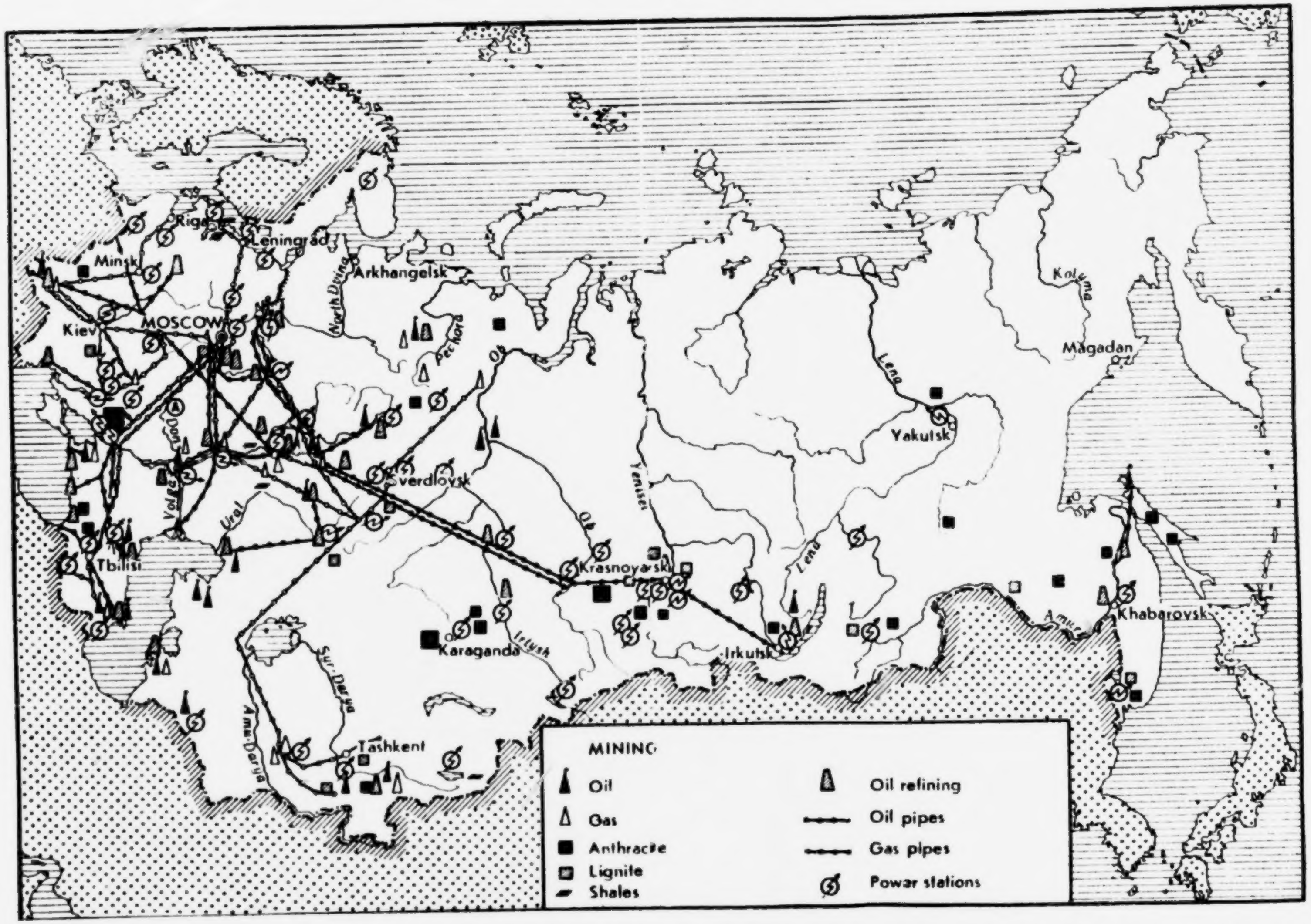

Kaliningrad
Kekhra
Leningrad
Kovda
Murmansk
Byelomorsk
Daugavpils
Riga
Segezha
Lvov
Minsk
Onega
Arkhangelsk
Pinsk
Kuvshinovo
Rakhov
Gomel
Sokol
Naryan-Mar
Kiev
Pechora
Odessa
MOSCOW
Kharkov
Volzhsk
Kirov
Krasnovishersk
Dniepropetrovsk
Igarka
Saratov
Kazan
Krasnokamsk
Tavda
Volgograd
Kuibyshev
Ufa
Tyumen
Astrakhan
Ust-Kamchatsk
Peledui
Poronaisk
Komsomolsk-on-Amur
Sovietskaya Gavan
Yuzhno-Sakhalinsk
Omsk
Krasnoyarsk
Novosibirsk
Tomsk
Bratsk
Blagoveshchensk
Khabarovsk
Barnaul
Abekan
Kansk
Zima
Baku
Irkutsk
Chita
Iman
Vladivostok
Tashkent
Industry:
Timber-sawing and wood-working
Paper
Principal lumbering areas
Forests
500
0
500
1000 km

PRINCIPAL CENTERS OF THE FOOD INDUSTRY IN THE U.S.S.R.


40
60
80
100
120
140
160
180
ARCTIC OCEAN
Murmansk
Leningrad
Petrozavodsk
Byelomorsk
Kandalaksha
Kaliningrad
Riga
Kalinin
MOSCOW
Rybinsk
Vologda
Onega
Mezen
Arkhangelsk
Naryan-Mar
Novy-Port
Ust-Port
Kiev
Poltava
Bryansk
Voronezh
Yaroslavl
Ivanovo
Syktyvkar
Salekhard
Beryozovo
Odessa
Dniepropetrovsk
Kherson
Kharkov
Gorky
Kirov
Perm
Khanty-Mansiisk
Simferopol
Kazan
Kuibyshev
Sverdlovsk
Saratov
Engels
Buguima
Ufa
Sterlitamak
Chelyabinsk
Kurgan
Petropavlovsk
Krasnodar
Rostov
Volgograd
Uralsk
Orenburg
Orsk
Stavropol
Astrakhan
Guryev
Omsk
Tomsk
Krasnoyarsk
Novosibirsk
Novokuznetsk
Barnaul
Biisk
Pavlodar
Semipalatinsk
Karaganda
Aralsk
Muinak
Tbilisi
Yerevan
Baku
Ashkhabad
Tashkent
Chimkent
Leninabad
Samarkand
Dushanbe
Osh
Frunze
Alma-Ata
Kyzyl
Irkutsk
Ulan-Ude
Chita
Borzya
Ust-Barguzin
Nizhne-Angarsk
Blagoveshchensk
Yakutsk
Lena
Kolyma
Magadan
Okhotsk
Ayan
Nikolayevsk-on-Amur
Komsomolsk-on-Amur
Sovietskaya Gavan
Khabarovsk
Nevelsk
Ussuriisk
Nakhodka
Vladivostok
Ust-Kamchatsk
Petropavlovsk-Kamchatsky
Bolsheretsk
Severo-Kurilsk
Korsakov
Poronaisk
40
80
Food industry
Flour-milling industry
Meat industry
Fish and fish packing industry

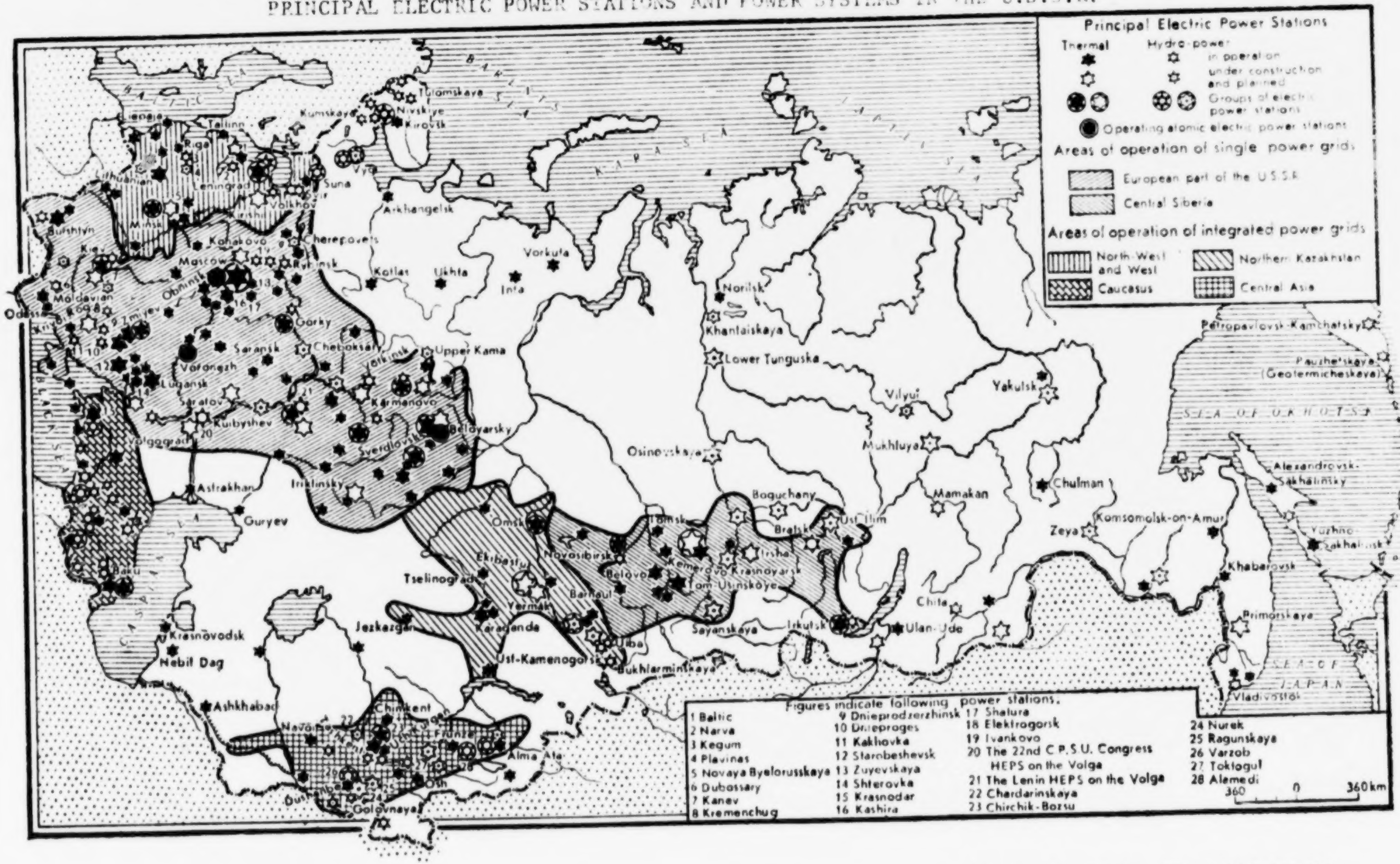
(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

THE MAIN MINING CENTERS OF THE USSR


Riga
Leningrad
Minsk
Arkhangelsk
North Dvina
Kiev
MOSCOW
Pechora
Ob
Don
Volga
Ural
Sverdlovsk
Tbilisi
Yenisei
Lena
Kolyma
Magadan
Yakutsk
Krasnoyarsk
Irtysh
Karaganda
Irkutsk
Amur
Khabarovsk
Syr-Darya
Amu-Darya
Tashkent
MINING
Oil
Gas
Anthracite
Lignite
Shales
Oil refining
Oil pipes
Gas pipes
Powar stations

(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL ELECTRIC POWER STATIONS AND POWER SYSTEMS IN THE U.S.S.R.


Principal Electric Power Stations
Thermal
Hydro-power
in operation
under construction and planned
Groups of electric power stations
Operating atomic electric power stations
Areas of operation of single power grids
European part of the U.S.S.R.
Central Siberia
Areas of operation of integrated power grids
North-West and West
Northern Kazakhstan
Caucasus
Central Asia
Figures indicate following power stations.
1 Baltic
2 Narva
3 Kegum
4 Plavinas
5 Novaya Byelorusskaya
6 Dubossary
7 Kanev
8 Kremenchug
9 Dnieprodzerzhinsk
10 Dnieproges
11 Kakhovka
12 Starobeshevsk
13 Zuyevskaya
14 Shterovka
15 Krasnodar
16 Kashira
17 Shatura
18 Elektrogorsk
19 Ivankovo
20 The 22nd C.P.S.U. Congress HEPS on the Volga
21 The Lenin HEPS on the Volga
22 Chardarinskaya
23 Chirchik-Bozsu
24 Nurek
25 Ragunskaya
26 Varzob
27 Toktogul
28 Alemedi
360 0 360km
BARENTS SEA
KARA SEA
BALTIC SEA
BLACK SEA
CASPIAN SEA
SEA OF OKHOTSK
SEA OF JAPAN
Tallinn
Riga
Leningrad
Minsk
Kiev
Moldavian
Odessa
Burshtyn
Volkhov
Kirishi
Suna
Kumskaya
Tulomskaya
Nivskiye
Kirovsk
Arkhangelsk
Cherepovets
Rybinsk
Konakovo
Moscow
Obninsk
Gorky
Saransk
Voronezh
Lugansk
Saratov
Kuibyshev
Volgograd
Cheboksary
Votkinsk
Upper Kama
Karmanovo
Sverdlovsk
Beloyarsky
Iriklinsky
Astrakhan
Guryev
Baku
Krasnovodsk
Nebit Dag
Ashkhabad
Navoi
Chimkent
Frunze
Alma-Ata
Osh
Dushanbe
Golovnaya
Kotlas
Ukhta
Vorkuta
Inta
Tselinograd
Jezkazgan
Karaganda
Ekibastuz
Yermak
Omsk
Novosibirsk
Barnaul
Belovo
Tomsk
Kemerovo
Krasnoyarsk
Tom-Usinskoye
Ust-Kamenogorsk
Bukhtarminskaya
Sayanskaya
Irkutsk
Bratsk
Ust-Ilim
Boguchany
Norilsk
Khantaiskaya
Lower Tunguska
Osinovskaya
Vilyui
Mukhluya
Mamakan
Yakutsk
Chulman
Zeya
Chita
Ulan-Ude
Komsomolsk-on-Amur
Khabarovsk
Primorskaya
Vladivostok
Alexandrovsk-Sakhalinsky
Yuzhno-Sakhalinsk
Petropavlovsk-Kamchatsky
Pauzhetskaya (Geotermicheskaya)

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

DISTRIBUTION OF AEROSOLS IN THE FREE ATMOSPHERE AROUND KRASNOYARSK

M. A. Belyashova

From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 238, p. 210-219, (1969).

It is common knowledge that a huge amount of aerosols, particularly condensation nuclei, reach the free atmosphere by being discharged from major industrial sources and from cities. Examples of the distribution of aerosols from such sources are given in a monograph [5].

This article discusses the distribution of aerosols and their transport in the free atmosphere over Krasnoyarsk. In 1965-1967, at different times of the year, V. G. Dedkov, A. A. Ignat'yeva, and N. I. Volkova, on the staff of an airplane sounding post, carried out 15 flights around the city. Each flight approximately followed the city limit at some distance from it, at heights of 300, 600, and 900 m above the earth's surface. Because of the complexity of the local topography, the distance of the outer contour from the city limits was different in different directions. The largest distance in the northern, southern and southwestern directions was 25-30 km, and in the western and eastern directions, 10-15 km.

Before and after the overflight, the atmosphere was sounded to a height of 3000 m. The total duration of the flight including the sounding lasted from 3 1/2 to 4-5 hours. In some cases, the flight along the external polygon at a height of 600 m was not carried out, then one sounding was excluded, and as a result the time investment was reduced to 2 hours.

The aerosol particle concentration was measured by means of a small-model Shol'ts counter specially adapted for in-flight observations [1].

The air samples were collected continuously, and the particle concentration was determined as the average of five measurements, which required 2-3 minutes. Thus, each value of the concentration of particles (or condensation nuclei) is an average characteristic for a distance of 6-9 km at the outskirts of the city and 10-15 km away from the city.

In such an arrangement of the observations, it is obvious that we cannot evaluate the distribution of aerosols directly over the city, but can only estimate the penetration of pollutants into the atmosphere from the city as a whole.

Unfortunately, we have only one point available for ground observations, and shall, therefore, confine ourselves to the consideration of the distribution of condensation nuclei in the free atmosphere from a height of 300 m.

The available data in relative units are listed in Tables 1 and 2; the numbers in parentheses were obtained by interpolation. The calculation was made in reference to the height of 300 m, taken as the initial level.

The total content of aerosols at any point of the city's environs consists of aerosols present in the air outside the city and aerosols arriving from urban sources. The suburban, or background aerosol concentration N_b was determined from measurements on the windward side of the city at the most distant points of the itinerary. An additional arrival of aerosols from urban sources may be defined as the difference $\Delta N' = N_i - N_b$. At the initial 300 m level, the highest concentrations of aerosol particles were usually observed on the leeward side. The calculation of the change in the aerosol concentration in space was made relative to these values.

$$\Delta N = \frac{N_i - N_b}{N_{\text{макс}} - N_b}.$$

The distribution of aerosols in the boundary layer of the atmosphere from major industrial sources strongly depends on the temperature stratification of the atmosphere, wind velocity, weather conditions and other meteorological factors.

It is therefore of interest to examine the distribution of aerosols in the city's environs as a function of the state of the atmosphere.

The atmospheric soundings that were carried out pertain to the outskirts of the city. Since the basic temperature differences between the urban and rural areas level off at a height of approximately 300 m [6], they can be neglected in this case.

Under anticyclonic weather conditions with a weak advection of the air masses and the presence of superadiabatic gradients, an enormous amount of aerosols reaches the free atmosphere. For example, on 29 March 1967, the aerosol particle concentration near the ground was 19.4×10^3 cm^{-3}, the average value on the windward side at the city limit was 1.4×10^3 cm^{-3} at a height of 300 m, with a minimum value of nuclei of 0.2×10^3 per cm^3 and a maximum value of 4.6×10^3 cm^{-3}; of the leeward side of the city, the number of particles increased to an average of 11.74×10^3 cm^{-3}, and their minimum value also increased by approximately 10 times ($N_{min} = 2.3 \times 10^3$ cm^{-3}), and the maximum value, 4 times ($N_{max} = 18.2 \times 10^3$ cm^{-3}).

At a height of 600 m an inversion of nuclei was observed in certain sections of the city's outskirts, but the average concentration on the leeward side was 10.84×10^3 cm^{-3} with a minimum of 20.5×10^3 cm^{-3}, i.e., the maximum concentrations exceeded the ground concentrations. Daytime heating promoted the development of convection and $\gamma > 1$ was observed up to a height of 500 m. Turbulence experienced by the airplane from the earth's surface to the lower cloud level (from $-0.25 + 0.25$ g) proved an intense mixing. At a height of 900 m above the convection level the amount of aerosols arriving from the city decreased by about 80% as compared to the height of 300 m (see Table 1 and Fig. 1 a), and the degree of atmospheric pollution on the leeward side of the city corresponded to the pollution at a distance of 20 km from the city. The influence of the city at this height was more even and less marked. On 30 March 1967, in the presence of a superadiabatic gradient up to a height of 300 m, an increase of the wind with height, and the presence of an inversion 50 m thick at a height of 500 m, the smoke from the city was carried to a distance of 15-20 km (see Fig. 1 b), its lower boundary was at a height of 190 m, and its upper boundary at a height of 520 m. Obviously, this layer of the atmosphere was the most heavily polluted. At the 300 m height, a relatively heavy accumulation of nuclei was observed which remained up to a distance of 20 km from the pollution source. Although the inversion layer was not thick, it hindered the transport of particles to greater heights. Thus, at the height of 600 m, the average aerosol concentration decreased by approximately 10 to 12 times relative to the concentration at 300 m, and at the height of 900 m, by 30-35 times. Despite such a marked decrease of aerosols with height, because of the inversion layer, the influence of the city along the main transport was manifested at the heights of both 600 m and 900 m, at a distance of over 20-30 km from the city. The aerosol maximum at the height of 600 m was noted at a distance of 20 km from the city, and at the height of 900 m, at 10 km.

Summer convection promotes the transport of aerosols to heights of over 1.5-2 km [5], and maximum concentration values may be found at a considerable distance from the source of pollutants [2, 3]. On 3 July 1967, at a height of 900 m, the maximum number of condensation nuclei was observed at a distance of 20 km from the city on the leeward side. At this distance, a certain tendency on the part of the nuclei to increase from the height of 300 m to the height of 900 m was observed (see also Table 1 and Fig. 1 c).

On 19 June 1967, the city and its environs were exposed to the influence of a low-gradient pressure field with weak northwestern winds; in the morning hours before the overflight of the city, a strong inversion 30 m thick was observed at the height of 900 m. The diurnal heating caused this inversion to dissipate and the temperature gradients to increase to adiabatic or close-to-adiabatic values (the values of gradient γ shown in square brackets pertain to sounding carried out after the overflight of the city's environs). The large amount of particles at the heights of 600 and 900 m was due to the development of diurnal convection (see Table 1).

In winter, in the presence of a temperature inversion, the main mass of pollutants was concentrated in the ground layer of the atmosphere. Thus, on 14 December 1966, the ground values of the concentration were approximately 100 times the particle concentrations at the height of 300 m. The smog boundaries were observed to extend from earth's surface to 250 m. Despite the fact that a light snow was falling and that there was a thick temperature inversion, the individual smoke discharges pierced the inversion layer, and the influence of the city could be readily followed at all heights; the maximum pollution values were observed at the height of 600 m; because of

Dispersal of Aerosols From the City (in Relative

Date	Time of Take-off, hr, min.	$H=300$ m								
		γ	$d-v$	Distance from the City, km						
				Windward Side			City			Leeward
				30	20	10				10
16 III 1966	11 02	−0,20	270−9	0	0,00	0,01	0,14	1,00	0,56	0,10
27 III 1967	13 26	0,70	240−4	0			0,18	0,74	1,00	0,21
28	11 10	0,84	230−1	0	0,01		0,13	0,83	1,00	0
29	10 17	1,56	350−4	0	0	0	0,06	1,09	0,76	
30	11 00	1,13	220−4	0		0,01	0,04	0,79	1,00	0,67
14 XII 1966	10 23	−0,83	190−3	0		0	0,93	1,00	0,33	0,00
5 X 1967	9 42	1,00	280−2	0	0,05	0,07	0,24	1,00	0,75	0,13
15 IX 1965	11 38	−1,98	160−3	0	0		1,00	0,92	0,33	
12 IX 1966	10 01	−0,07	075−2		0		0,14	1,00	0,69	1,04
3 V 1967	9 39	−1,17	240−4	0		0,06	0,42	0,71	1,00	0,64
14 VI 1967	10 12	0,75	280−7	0		0	0,13	0,21	1,00	0,52
19	9 41	[0,90] 0,13	070−3			0,18	1,00	0,91	0,97	0,25
22	8 05	0,83	240−10	0		0	0,42	0,77	1,00	0,15
3 VII 1967	8 43	1,00	080−2		0	0,04	1,00	0,90	0,56	
4 VII 1967	7 56	−0,60	300−2	0		0,01	0,26	0,64	1,00	0,25

Date	Time of Take-off, hr, min.	$H=900$ m						
		γ	$d-v$	Distance from the City,				
				Windward Side			Ci	
				30	20	10		
16 III 1966	11 02	0,83	270−9	0		0	0,00	0,09
27 III 1967	13 26	0,91	260−5	0	0,01		0,08	0,16
28	11 10	0,44	350−3	0		0,01	0,01	0,06
29	10 17	0,69	330−3	0		0	0,03	0,12
30	11 00	0,94	220−6	0		0	0,01	0
14 XII 1966	10 23	0,17	250−4	0		0	0,17	0,19
5 X 1967	9 42	0,52	250−4	0		0,02	0,02	0
15 IX 1965	11 38	−0,94						
12 IX 1966	10 01	0,33	120−5			0	0	0
3 V 1967	9 39	(−1,67)	260−8		0	0,06	0,17	0,25
14 VI 1967	10 12	0,92	290−9	0		0	0	0,07
19	9 41	[1,00] −1,67	060−4			0,33	0,45	0,50
22	8 05	0,48	250−13	0		0	0	0,03
3 VII 1967	8 43	−0,76	080−6		0	0	0,01	0,02
4 VII 1967	7 56	−1,07	020−3	0	0,01	0,01	0	0

Table 1

Units) Along the Direction of the Wind.

		H—600 m										
				Distance from the City, km								
Side		τ	d - v	Windward Side			City			Leeward Side		
20	30			30	20	10				10	20	30
0,15		0,83	270—11	0	0		0,06	0,16	0,26	(0,09)	(0,012)	
0,14	0,06	0,70	250—4	0			0,08	0,34	0,34	(0,15)	(0,11)	
0,01	0	0,05	340—2									
0,18	0,01	0,74	310—2	(0)	(0)		0,03	1,09	0,76		(0,22)	(0,05)
0,69	0,00	(—0,60)	210—5	(0)		(0)	0,05	0,09	0,04	(0,03)	(0,27)	(0,05)
0,00	0	—0,17	330—3	0		0,37	0,46	1,25	1,09	0		0
0,06		0,98	280—3		(0,01)		0,14	0,35	0,26	(0,06)	(0,02)	
0,34	0,22	0,39	250—7	0	0	(0,03)	0,02	0,02	0,01	0	(0,02)	
0,45		—0,67	090—3			0	0	0	0	0,36	0,29	
	0,09	0,68	240—8	0		(0,07)	0,22	0,23	0,31	(0,34)		(0,13)
		0,75	280—9	0		0	0,03	0,06	0,41	(0,25)		
	0	[0,96] 0,76	020—3			(0,35)	0,76	0,34	0,41	(0,35)		0
0,68	0,22	0,82	260—13	0			0,11	0,15	0,49	(0,39)	(0,34)	(0,08)
0,43		1,00	080—5			(0,02)	0,25	0,44	0,30		(0,45)	
	0	0,00	360—2	0	0	(0,03)	0	0	0,11	(0,13)		(0,01)

km				Remarks
	Leeward Side			
ty	10	20	30	
0,31	0,20	0,11		10/1 Ac, Sc, northeastern part of anticyclone
0,06	0,03	0,04		10/0 Ci, Cs, northwestern part of anticyclone
0,04	0,03	0	0	10/4 As, Ac, Sc, ✳°, light smoke, cyclone
0,22		0,20	0,02	3/3 Cu, crest of anticyclone
0,03	0,39	0,21		4/0 Ci, Ac, light smoke, southeastern periphery of cyclone
0,52	0,30			10/0 Cs, ✳°, heavy smoke, calm, ∞°, anticyclone
0	0	0		4/0 Ci, smoke, spur of anticyclone
				10/0 Ac, =°, anticyclone
0,11	0,13	0,25	0,87	0/0, =, anticyclone
0,32	0,03		0,02	0/0, ∞°, calm, anticyclone
0,16	0,29			9/6, Cu, Ac, Ci, rear of cyclone
0,31	(0,35)		0	3/0 Ci, light smoke, col
0,03	0,03		0	10/10 Frnb, Cb, Sc, $\dot{\nabla}$, occluded cyclone
0,02		0,49		8/2 Ci, Cu, fr, calm, cyclone
0,01	0,01		0,01	8/4 Ac, Cu, occluded cyclone

Lateral Dispersal of Aerosols at Right Angles to the Forward Flow

Date	Time of Take-off hr,min.	Distance From									
		30	20	10	City			10	20	30	30
					$H=300$ m						
16 III 1966	11 02	0,02	0,07	0,15	0,81	1,00	0,33	0,04		0	(0,03)
27 III 1967	13 26	0,06	0,05	0,02	0,43	1,00	0,74	0,04	0,04	0	(0,05)
28 III 1967	11 10	0	0,02	0,01	0,29	1,00	0,82				
29	10 17	0,01	0,01	0,03	0,50	1,00	0,76	0,25	0,01	0	
30	11 00	0	0,03	0,21	1,00	0,79	0,79		0	0	(0)
14 XII 1966	16 23	0	0	0,50	0,67	0,93	1,00	0,20	0,04		0,00
5 X 1966	9 42	0,04	0,06		0,39	0,75	1,00	0,09	0,09	0,03	0,01
15 IV 1965	11 38		0,04	0,04	0,92	1,00	0,52	0,37	0,24	0,06	0
12 IX 1966	10 01	0,21	0		0,22	0,42	1,00	0,59		0	0.87
3 V 1967	9 39		0,03	0,09	0,38	1,00	0,71	0,03		0,06	(0,17)
14 VI 1967	10 02	0		0	0,40	1,00	0,21	0,02		0	(0)
19 VI	9 41	0,06	0,04	0,06	0,87	1,00	0,97	0,25		0	(0,05)
22	8 05	0,22	0,12	0,03	0,81	1,00	0,77	0,09		0	(0,10)
3 VII 1967	8 43	0,15	0,17	0,21	0,42	1,00	0,90		0	0	(0,08)
4 V	7 56	0,03	0,02	0,01	0,19	1,00	0,71	0,36		0	(0,03)

the turning of the wind with the height and its weak force, the influence of the city along the direction of the wind at the heights was limited to a distance of 10-15 km, but the lateral dispersal (perpendicular to the wind) manifested itself within a radius of 20 km because of diffusion. However, the flow of nuclei along the direction of the wind exceeded the flow due to the lateral dispersal, i.e., the dispersal of aerosols along the main transport was much faster than the lateral dispersal (see Tables 1, 2, 3).

It is evident from Tables 1 and 2 that the dispersal of aerosols both along the main transport and laterally takes place within a radius of over 30 km.

The horizontal exchange coefficient for mesoscale turbulence and the flow of nuclei from the city were determined by methods used earlier by Ye. S. Selezneva [5]:

$$K=\frac{\sigma^2}{2t},$$

where σ is the deviation of the boundaries of the aerosol cloud from the initial boundaries corresponding to the width of the source; t is the time of aerosol dispersal, which may be assumed equal to the ratio of the distance from the source of discharges (from the city) to the wind velocity

Table 2

From the City (in Relative Units).

City, km

20	10	City			10	20	30	30	20	10	City			10	20	30
$H=600$ m								$H=900$ m								
(0,13)	(0,10)	0,51	0,16	0,03	(0,07)		(0)	0,03		0,09	0,32	0,08	0,02	0,09		0
(0,05)	(0,08)	0,24	0,34	0,13	(0,05)		0	0,03	0,02	0,04	0,16	0,06	0,16	0,01		0,01
								0		0,01	0,03	0,04	0,06	0,01		
(0,01)	(0.12)	0,18	1,00	1,09	(0,13)	(0,01)	0	0	0,01	0,01	0,01	0,12	0,52	0,03	0,22	
(0,03)	(0,04)	(0,04)	0,09	0,01	0,01		0	0,01	0,01	0,02	0,00	0.03	0,01	0,01	0.01	0,01
0,01	0,12	1,05	1,22	1,05	0,30		0	0	0,03	0,13	0,59	0,59	0,37	0,13	0,07	
0,01	0,01	0,18	0,30	0,38	0,08	0,08	0,01	0,01	0	0	0	0	0	0,06	0,03	0,01
0,02		0,02	0,01	0,02	0,02	0										
0,22	0,36	0	0	0	0	0	0	0,87	0,57	0,50	0	0	0	0,54	0,17	
(0,16)	(0,33)	0,23	0,31	0,30	(0,04)		(0,03)	0,05	0,07	0,04	0,16	0,33	0,31	0,06	0	
	(0,02)	0,16	0,42	0,08	(0,13)		(0)	0	-	0,05	0,02	0,17	0,07	0,23	0	
(0,05)	0,04	0,22	0,72	0,40	(0,34)		0	0,04	0,05	0,02	0,25	0,45	0,31	(0,35)		
(0,02)	0	0,38	0,49	0,15	(0,04)		(0,02)	0	0	0,03	0,03	0,03	0	0,03	0	
(0,10)	(0,12)	0,17	0,25	0,44	0		0	0,02	0,06	0,10	0,02	0,02	0,02	0	0	
(0,01)	(0,01)	0	0,02	0,09	0,18	0,03		0,01	0,01	0,01	0,01	0,00	0,01	0,01	0,01	

in the observation layer.

We find by calculation that the horizontal exchange coefficient ranges from 0.5 x 10^8 to 0.5 x 10^9 cm^2/sec (see Table 3). The order of values of K is in good agreement with the data of reference [5].

The flow of nuclei resulting from lateral dispersal $P_y = K \frac{\partial N}{\partial y}$ is one order of magnitude less than the flow of condensation nuclei in the direction of the main transport, which is equal to the sum of the directed and turbulent transport

$$P_x = P'_x + P''_x = u\overline{N} + K\frac{\partial N}{\partial x}.$$

At the same time, it should be noted that in the presence of a temperature inversion and a weak wind on 14 December 1966, the flow of nuclei along the main transport and with lateral dispersal was one order of magnitude less than the flows on the remaining days.

The spreading of pollutants from the city to greater distances can be followed from the results of horizontal flights. In a flight under anticyclonic conditions along the direction of the main air flow at a height of about 1000 m in the northern direction, on 25 April 1967, the influence of the city was observed up to a distance of 220 km; on 26 October 1966 and 28 December 1966, from 160 to 180 km; in the southwestern direction on 24 June 1965, up to 140 km; on 24 August 1965, up to 250 km.

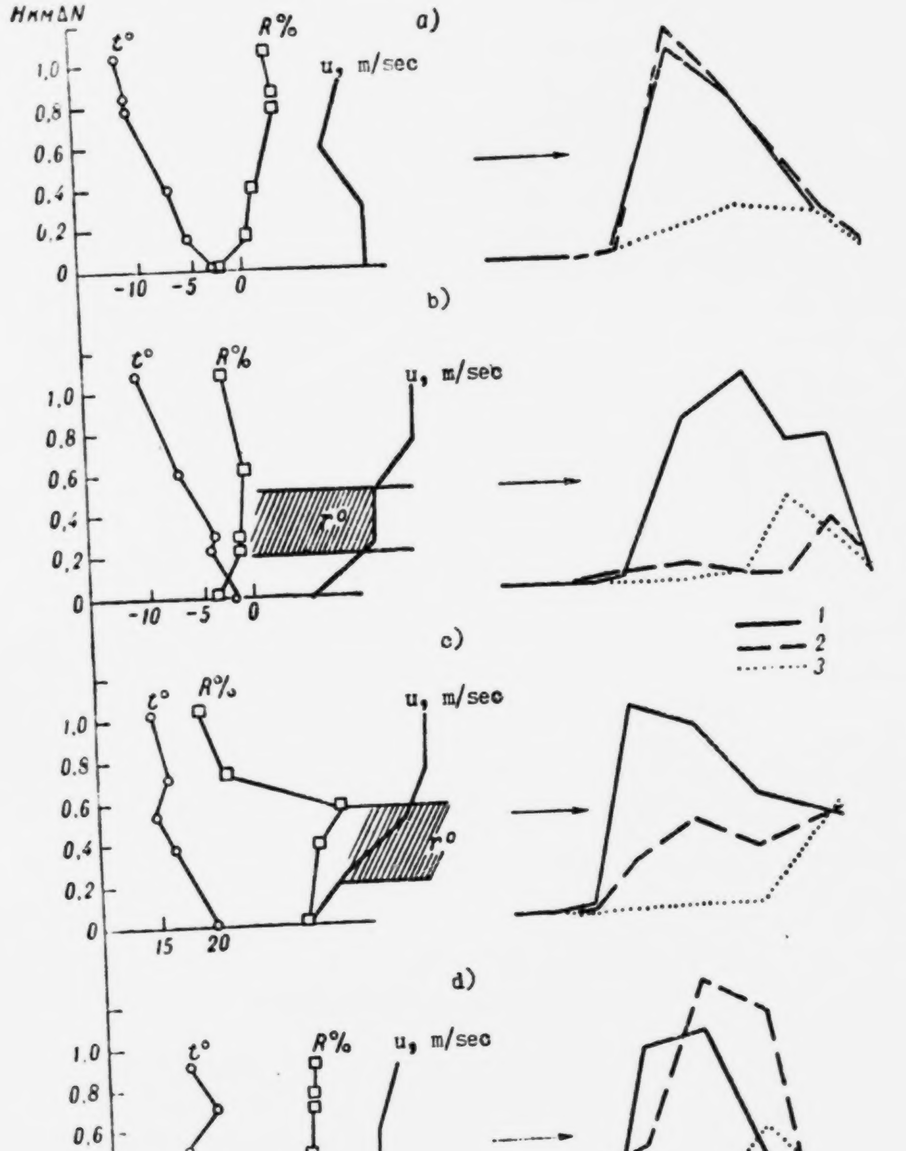


Fig. 1. Distribution of meteorological elements (t°, R% and m/sec) with height and of condensation nuclei in relative units along the direction of the wind over the outskirts of the city and its environs at heights of 300 m (1), 600 m (2) and 900 m (3).
a) 29 III 1967, b) 30 III 1967, c) 3 VII 1967, d) 14 XII 1966.

Table 3

Some Parameters of Aerosol Dispersal at Height of 300 m above City and its Environs.

Date	Time of Take-off, hr, min	Size of Source e, km	Distance From Source L, km	Δy (σy)	u, m/sec	t, sec	k	$\overline{N}$	$\frac{\partial N}{\partial x}$	$\frac{\partial N}{\partial y}$	P_y	P'_x	P_x
16 III 1966	11 02	15	5	6	9	$5{,}6\cdot10^{2}$	$3{,}2\cdot10^{8}$	$3{,}4\cdot10^{3}$	$0{,}7\cdot10^{-2}$	$1{,}3\cdot10^{-3}$	$4{,}2\cdot10^{5}$	$3{,}1\cdot10^{6}$	$4{,}3\cdot10^{6}$
27 III 1967	11 10	15	5	5	4	$1{,}2\cdot10^{3}$	$1{,}0\cdot10^{8}$	$11{,}6\cdot10^{3}$	$2{,}3\cdot10^{-2}$	$4{,}6\cdot10^{-3}$	$4{,}6\cdot10^{5}$	$4{,}6\cdot10^{5}$	$6{,}9\cdot10^{6}$
28 III 1967	11 59	15	10	10	1	$1{,}0\cdot10^{4}$	$0{,}5\cdot10^{8}$	$7{,}9\cdot10^{3}$	$7{,}9\cdot10^{-3}$	$2{,}3\cdot10^{-3}$	$1{,}2\cdot10^{5}$	$7{,}9\cdot10^{5}$	$1{,}2\cdot10^{6}$
29 III 1967	10 17	35	10	10	4	$2{,}5\cdot10^{3}$	$2{,}0\cdot10^{8}$	$11{,}7\cdot10^{3}$	$11{,}7\cdot10^{-3}$	$2{,}1\cdot10^{-3}$	$4{,}2\cdot10^{5}$	$4{,}7\cdot10^{6}$	$7{,}1\cdot10^{6}$
30 III 1967	11 00	20	8	5	4	$2{,}0\cdot10^{3}$	$6{,}3\cdot10^{7}$	$16{,}9\cdot10^{3}$	$2{,}1\cdot10^{-2}$	$5{,}6\cdot10^{-3}$	$3{,}5\cdot10^{5}$	$6{,}8\cdot10^{6}$	$8{,}1\cdot10^{8}$
14 XII 1967	10 23	35	10	7	3	$3{,}3\cdot10^{3}$	$7{,}4\cdot10^{7}$	$0{,}8\cdot10^{3}$	$0{,}8\cdot10^{-3}$	$1{,}6\cdot10^{-4}$	$1{,}2\cdot10^{4}$	$2{,}4\cdot10^{5}$	$0{,}3\cdot10^{8}$
5 X 1967	9 42	15	10	10	2	$5{,}0\cdot10^{3}$	$1{,}0\cdot10^{8}$	$8{,}9\cdot10^{3}$	$8{,}9\cdot10^{-3}$	$2{,}5\cdot10^{-3}$	$2{,}5\cdot10^{5}$	$1{,}8\cdot10^{6}$	$2{,}7\cdot10^{8}$
15 IX 1965	11 38	30	20	10	3	$6{,}7\cdot10^{3}$	$7{,}5\cdot10^{7}$	$9{,}6\cdot10^{3}$	$4{,}8\cdot10^{-3}$	$1{,}9\cdot10^{-3}$	$1{,}4\cdot10^{5}$	$2{,}9\cdot10^{6}$	$3{,}3\cdot10^{6}$
12 IX 1966	10 01	15	20	30	2	$1{,}0\cdot10^{4}$	$4{,}5\cdot10^{8}$	$1{,}9\cdot10^{3}$	$9{,}5\cdot10^{-4}$	$2{,}5\cdot10^{-4}$	$1{,}1\cdot10^{5}$	$3{,}8\cdot10^{5}$	$8{,}1\cdot10^{5}$
3 V 1967	9 39	15	10	5	4	$2{,}5\cdot10^{3}$	$0{,}5\cdot10^{8}$	$4{,}7\cdot10^{3}$	$4{,}7\cdot10^{-3}$	$1{,}9\cdot10^{-3}$	$1{,}0\cdot10^{5}$	$1{,}9\cdot10^{6}$	$2{,}1\cdot10^{6}$
2 V 1967	9 53	30	10	10	4	$2{,}5\cdot10^{3}$	$2{,}0\cdot10^{8}$	$1{,}5\cdot10^{3}$	$1{,}5\cdot10^{-3}$	$0{,}3\cdot10^{-3}$	$1{,}2\cdot10^{5}$	$6{,}0\cdot10^{5}$	$0{,}9\cdot10^{6}$
14 VI 1967	10 02	15	5	5	7	$7{,}1\cdot10^{2}$	$1{,}8\cdot10^{7}$	$4{,}3\cdot10^{3}$	$8{,}6.10^{-3}$	$1{,}7\cdot10^{-3}$	$3{,}1\cdot10^{5}$	$3{,}0\cdot10^{6}$	$4{,}5\cdot10^{6}$
19 VI 1967	9 41	15	10	10	3	$3{,}3\cdot10^{3}$	$1{,}5\cdot10^{8}$	$15{,}6\cdot10^{3}$	$15{,}6\cdot10^{-3}$	$4{,}5\cdot10^{-3}$	$6{,}8\cdot10^{5}$	$4{,}7\cdot10$	$7{,}0\cdot10^{6}$
22 VI 1967	8 05	15	10	6	10	$1{,}0\cdot10^{3}$	$1{,}8\cdot10^{8}$	$3{,}9\cdot10^{3}$	$3{,}9\cdot10^{-3}$	$1{,}4\cdot10^{-3}$	$2{,}5\cdot10^{5}$	$3{,}9\cdot10^{5}$	$6{,}2\cdot10^{6}$
3 VII 1967	8 43	15	20	15	3	$6{,}7\cdot10^{3}$	$1{,}7\cdot10^{8}$	$9{,}7\cdot10^{3}$	$4{,}8\cdot10^{-3}$	$2{,}1\cdot10^{-3}$	$3{,}6\cdot10^{5}$	$2{,}9\cdot10^{6}$	$3{,}6\cdot10^{6}$
4 VII 1967	7 56	15	10	15	4	$2{,}5\cdot10^{3}$	$4{,}5\cdot10^{8}$	$9{,}9\cdot10^{3}$	$9{,}9\cdot10^{-3}$	$2{,}2\cdot10^{-3}$	$9{,}9\cdot10^{5}$	$4{,}0\cdot10$	$8{,}4\cdot10^{6}$

The lateral dispersal at the same height is manifested from 30-50 km to 80-110 km. Under cyclonic weather conditions during precipitation, the aerosols are washed out; their content depends on the intensity, type and duration of precipitation, and the distance to which the urban impurities are carried is reduced to zero. For example, on 10 December 1966, no transport of aerosols was observed whatsoever.

According to literature sources [3], atmospheric pollution produced by industrial regions of central England in the presence of eastern winds and a weak turbulence were quite distinguishable at a distance of 300 km.

To compare the degree of atmospheric pollution produced by a large industrial city and a small one, we shall examine the results of vertical sounding in the vicinity of such cities.

Fig. 2 shows the average distribution of the concentration of condensation nuclei on the basis of 11 ascents carried out in 1961-1962 near Krasnoyarsk and Yeniseysk; the shift in sounding time amounted to 2-4 hours.

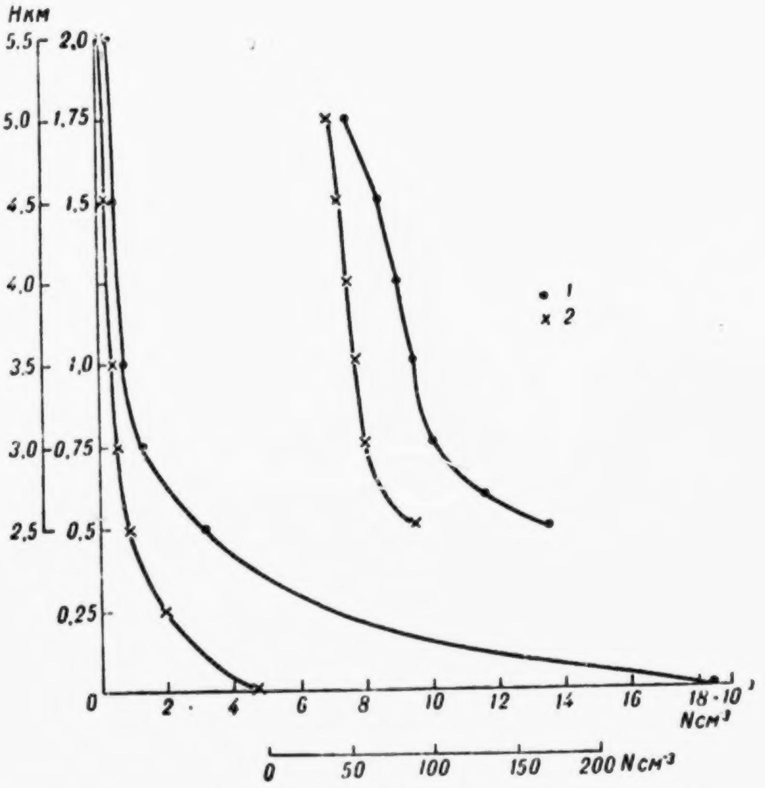


Fig. 2. Average distribution of condensation nuclei with height in the regions of Krasnoyarsk (1) and Yeniseysk (2) from 11 soundings.

In the entire thickness of the atmosphere, starting from the earth's surface and up to a height of 5 km, the environs of Krasnoyarsk are more heavily polluted than those of Yeniseysk, thus being particularly noticeable in the boundary layer of the atmosphere. Thus, at the earth's surface and in the layers in contact with it in the region of Yeniseysk, there are 3-4 times less aerosols than in the environs of Krasnoyarsk. This is also amply supported by data from studies of the chemical composition of subinversion clouds in regions of western Siberia [4]: the cloud water in the region of Yeniseysk is less mineralized than that in the environs of Krasnoyarsk.

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SPECTRAL METHOD OF DETERMINATION OF A SERIES OF ELEMENTS IN ATMOSPHERIC AEROSOLS

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From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 234, p. 196-204, (1968).

Data on the chemical composition of aerosols polluting the air of cities and on the change of this composition in time are of major interest for services controlling air pollution.

At the present time, suction methods are employed for determining the concentration of aerosols in air, and sedimentation methods are used for determining the density of their settling on a horizontal surface. In the subsequent ashing of the collected aerosol samples, one can determine the ratio of the organic to the inorganic fraction of the pollutants they contain. However, during a limited time interval it is difficult to obtain a sample of dust deposit of more than a few milligrams. Ordinary methods of chemical analysis of such small amounts of aerosol are ineffective [1]. Spectral methods, however, make it possible to measure the concentration of a large number of metals simultaneously, even in a small amount of analyzed material.

In the method considered for the quantitative spectral determination of the most common metals present in the composition of the inorganic fraction of atmospheric aerosols, a small amount (≈2 mg) of dust deposit is used, no greater than that usually collected by a network of stations in single measurements.

Results of preliminary experiments have shown that such metals as Al, Fe, Ca, and Mg are present in the largest amounts in the samples, their relative concentration ranging from 0.1 to 10%, while the relative concentration of Mn, Pb, Ni, Cu, and Zn ranges from 0.01 to 1%. In the development of the technique, consideration was given to the detected range of variation in the concentration of the indicated elements, and also to the requirements for a high absolute sensitivity and sufficient accuracy of these measurements.

In many cases, these requirements can be met by using the method of spectrum excitation with a sample attached to the end of a carbon electrode [2]. Preliminary experiments have shown that such a method can also be used for analyzing an aerosol deposit.

The measurement technique consists in the following. The sample to be analyzed is deposited on a carbon electrode 6 mm in diameter, by rubbing in.

The electrode end has been ground and has at its center a cavity 2 mm in diameter and 1 mm deep. The rubbing-in procedure places the entire sample in this cavity, and the sample is secured in the cavity with a 3% solution of polystyrene in benzene. The amount of sample thus secured is 2 mg. The constancy of the amount of sample deposited on the electrode is characterized by a mean square error of 13%.

The photographs were taken on an ISP-28 spectrograph in a 220 alternating current arc at a current intensity of 10 A. A three-lens slit illumination system was employed. The slit width of the spectrograph was 10 μ. The spectrum was photographed through a three-stage platinum attenuator on spectral plates (type II). The exposure was chosen on the basis of the burn-up time of the sample and was equal to 45 sec.

A carbon electrode with a truncated end served as the upper electrode. The distance between the electrodes was 2 mm. In order to improve the conditions of burning of the arc and to eliminate the mutual influence of the elements, 1 mg of sodium chloride, deposited on the electrode from a solution containing 10 mg/ml of sodium chloride, was added to all the samples to be analyzed. The following spectral lines were selected for the measurements:

Al 2652,48 Å (1),
Fe 2599,39 Å (2),
Ca 3158,86 Å (3),
Mg 2795,53 Å (1),
Mn 2801,06 Å (2),
Ni 3050,81 Å (2),
Zn 3345,57 Å (2),
Cu 3247,54 Å (1),
Pb 2833,07 Å (2).

The number of the stage of the 3-stage attenuator used for photometering the indicated line is shown in parentheses.

In the determination of the concentration of elements in the samples, calibration graphs were plotted; the difference of blackenings between the photometered line and the background around the line (ΔS) was laid off along the vertical axis, and the logarithm of the relative concentration of the element being determined ($\log C$) was laid off along the horizontal axis. The elements present in the samples in different concentrations affect each other, influencing the accuracy of the measurements. In order to check this influence, in the development of the spectral method, four series of quartz-base standards were prepared containing all the elements to be determined in the same quantitative relationship, in order to cover the entire range of possible concentrations (Table 1).

In the first series of standards as compared with the others, a certain increase in the spectral line intensity of Mn, Pb, Ni, Cu, and Zn is observed. In the second and third series of standards, the line intensity of these elements, taken in the same concentration, is constant, and in the fourth series a decrease of the line intensity is observed.

Table 1

Proportions of Elements in Standards, %

No. of Series	Elements	
	Fe, Al, Ca, Mg	Mn, Pb, Ni, Cu, Zn
1	10	0,001, 0,01, 0,1, 1
2	1	0,001, 0,01, 0,1, 1
3	0,1	0,001, 0,01, 0,1, 1
4	0,01	0,001, 0,01, 0,1, 1

In order to eliminate the fluctuations of line intensities and to stabilize the excitation conditions, sodium chloride is frequently employed. It was established experimentally that for a given quantity of analyzed sample (2 mg), the addition of 1 mg of sodium chloride, which, as indicated above, is deposited on the electrode from solution, completely eliminates the influence of Al, Fe, Ca, and Mg, which are present in different concentrations, on the determination of the remaining elements. When sodium chloride is introduced, the slope of the calibration graphs becomes the same for all the series of standards. As an example, Fig. 1 a shows calibration graphs for the determination of air, Fe and Mg, and Fig. 1 b, the calibration graphs for the determination of Mn, Cu, and Ni.

The use of a 3-stage attenuator will permit a substantial extension of the range of determinable concentrations for such common elements as Fe, Al, Ca, and Mg, up to 10%.

The accuracy and reproducibility of the method were checked by the "introduced - found" method, and for a number of samples, in order to bring out the "oversights", the results were compared with data of semiquantitative analysis by using a method proposed by M. M. Kler. However, the introduction of sodium chloride does not completely eliminate the influence of interfering elements on the determination of Zn. For this reason, the accuracy of the determination of zinc is characterized by a mean square error of 20%, whereas for the remaining elements it is 6-12%. Thus, for an accuracy of weighing of the sample of ±0.2 mg, the total error in the determination of the content of the different elements in the sample is ±30% for Zn and ±16-22% for the remaining elements.

Twenty-six aerosol samples were analyzed by using this technique. Of these, 24 samples were obtained by means of a board (b) and a board with flanged edges (bf), and 2 samples by means of a filtering-ventilating apparatus (FVA) in Leningrad. Results of the determination of the concentration of the various elements in aerosol samples collected by means of the FVA are listed in Table 2.

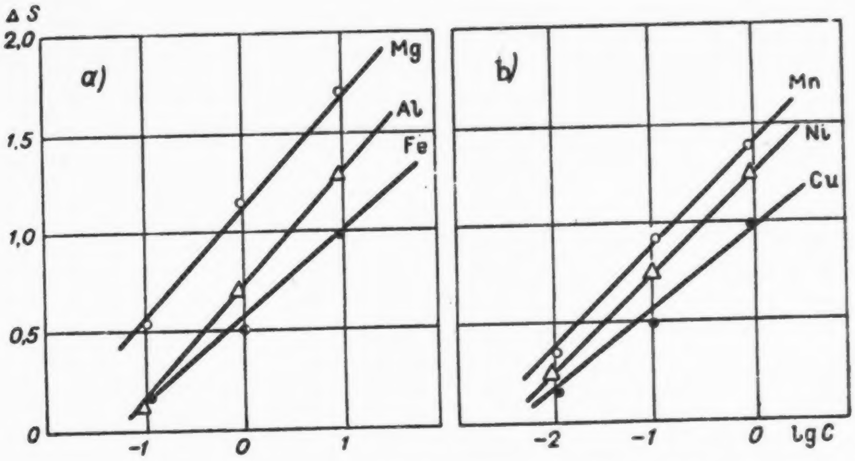

Fig. 1. Elevation graphs for determining Al, Fe, Mg (a); Calibration graphs for determining Mn, Ni, Cu (b).

It should be noted that in addition to the 11 elements given in the Table, the presence in the aerosol samples of a number of other elements was observed in the preliminary analysis, whose relative concentration in this sample was less than 0.002%, namely, Be, Ga, Ba, and Sr. Mo was observed once, and its concentration in the sample was 0.07%.

Table 2

Concentration of Different Components of Dust in Air, μg/m³.

Element	1963 r.		Element	1963 r.	
	3—4 IX	4—5 IX		3—4 IX	4—5 IX
Al	12,2	6,33	Cr	0,063	0,013
Mg	1,69	0,53	Cu	0,074	0,040
Ca	10,13	8,32	Pb	0,011	0,008
Fe	13,08	3,30	Zn	0,211	0,132
Mn	0,042	0,026	Ti	0,042	0,040
Ni	0,042	0,007			

Data on the concentration of certain elements in the cities of the U.S.A. are given in [1]. Each city is characterized by its own relative distribution of elements. Attention is drawn to the fact that the concentration of Pb in the cities of the U.S.A. is several orders of magnitude higher than in Leningrad. This is due to the fact that in the U.S.A., lead compounds are widely employed as antiknock gasoline additives.

Analysis of board samples collected simultaneously showed a fairly stable relative distribution of elements occurring in large quantities in the samples (Al, Mg, Ca, and Fe), confirming the reliability of the given technique. For elements present in microconcentrations in the samples, this stability is somewhat lower, apparently because their concentrations are close to the threshold values for the given method. As an example, Table 3 lists relative concentrations of the elements in the samples.

From the known weight of the sample and its relative concentration of the elements being determined, their absolute quantity is calculated.

Table 3

Relative Concentration of Elements Determined in the Inorganic Fraction of Dust by the Spectral Method in % of Weight of Sample.

Date	30—31 V		31 V—1 VI		3—4 IX		27—28 VI	
	1962				1963			
Sample No.	1	2	3	4	5	6	7	8
Element	bf	b	b	bf	bf	b	bf	b
Al	4,7	4,2	3,6	4,0	3,2	5,5	6,3	6,0
Mg	0,75	0,55	1,25	1,10	0,3	0,55	1,0	1,0
Ca	6,4	6,8	4,0	3,5	3,7	4,2	2,5	2,5
Fe	5,5	4,5	6,8	7,4	5,2	5,7	5,3	4,3
Mn	0,015	0,008	0,015	0,02	0,02	0,01	0,02	0,02
Ni	0,01	0,02	0,01	0,01	0,02	0,015	0,02	0,01
Cr	0,009	0,009	0,01	0,01	0,01	0,01	0,02	0,01
Cu	0,015	0,015	0,01	0,009	0,035	0,035	0,02	0,03
Pb	0,001	0,003	0,002	0,003	0,001	0,001	0,001	0,005
Zn	0,07	0,04	0,07	0,06	0,06	0,08	0,2	0,25
Ti	0,3	0,3	0,3	0,25	0,006	0,02	0,006	0,005

Table 4 lists results of the determination of the content of various elements in the inorganic fraction of dust, and also the amount and type of precipitation, direction of the wind and its average velocity during the period of exposure of the boards.

Analysis of the data of the table shows a certain relationship between the amount of each element taken separately or their sum in the samples and the meteorological phenomena.

For example, during precipitation, an increase is observed in the amount of the inorganic fraction of dust, total metallic elements in this fraction, and each individual element (samples of 19-21, 21-22, 26-27, 31 May-1 June 1962).

In the absence of precipitation and wind (samples from 6-9, 16-17 May 1962), the seizing properties of the board and of the board with flanged edges were almost identical for the total elements as well as for each individual element; therefore, the ratio $\frac{b}{bf}$ for each of the elements was close to unity.

Table 4

Elements Determined in the Inorganic Fraction of Dust in Leningrad Collected by Means of Boards (b) and Boards with Flanged Edges (bf), mg/m^3.

Element	30—31 I 1962			5—7 V 1962			8—9 V 1962			16—17 V 1962		
	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$
Al	14,2	12,7	1,12	13,20	28,20	0,47	8,59	8,38	1,03	6,62	4,01	1,65
Mg	1,85	2,03	0,91	1,80	6,55	0,28	4,00	3,45	1,16	2,72	2,12	1,28
Ca	22,9	17,3	1,33	24,90	39,30	0,74	10,88	11,55	0,87	7,82	5,08	1,61
Fe	15,2	14,9	1,02	21,60	32,30	0,67	3,58	3,32	1,08	5,94	4,72	1,26
Mn	0,027	0,041	0,66	0,120	0,101	1,19	0,086	0,106	0,81	0,068	0,106	0,68
Ni	0,067	0,027	2,48	0,030	0,025	1,20	0,012	0,011	1,09	0,017	0,012	1,44
Cr	0,031	0,024	1,29	0,018	0,040	0,45	0,012	0,007	1,71	0,017	0,011	1,60
Cu	0,050	0,041	1,22	0,027	0,050	0,54	0,010	0,013	0,77	0,002	0,017	1,18
Pb	0,010	0,003	3,34	0,006	0,010	0,60	0,008	0,003	2,67	0,005	0,0012	4,17
Zn	0,135	0,189	0,71	0,120	0,078	1,58	0,286	0,066	4,33	0,051	—	—
Ti	1,010	0,810	1,25	0,030	0,050	0,60	0,004	0,007	0,57	0,017	0,012	1,44
Σ	55,48	47,80		61,85	106,70		27,56	26,91		23,28	16,10	
Amount of Precipitation, mm	1,0	Snow		—			—			—		
Wind Velocity, m/sec	5,2			3,0			○			○		
Wind Direction	WSW			SE			—			—		

Table 4 (Cont'd)

Element	19—21 V 1962			21—22 V 1962			25—26 V 1962			26—27 V 1962		
	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$
Al	27,2	49,2	0,55	35,9	97,4	0,37	8,4	13,6	0,62	12,15	168,5	0,072
Mg	7,14	19,25	0,37	19,06	59,4	0,32	1,68	4,06	0,41	7,095	11,66	0,61
Ca	54,2	89,8	0,60	49,86	129,9	0,38	15,14	22,00	0,69	17,700	220,0	0,080
Fe	26,4	58,8	0,45	29,32	81,0	0,36	9,03	13,30	0,68	12,65	178,2	0,070
Mn	0,286	0,428	0,67	0,293	0,360	0,81	0,126	0,174	0,72	0,152	1,945	0,078
Ni	0,071	0,214	0,33	0,147	0,181	0,81	0,021	0,044	0,48	0,013	0,292	0,044
Cr	0,071	0,107	0,66	0,073	0,162	0,45	0,032	0,058	0,55	0,051	0,486	0,104
Cu	0,107	0,161	0,66	0,184	0,450	0,41	0,053	0,072	0,74	0,051	0,811	0,062
Pb	0,021	0,032	0,66	0,022	0,054	0,41	0,006	0,009	0,67	0,008	0,032	0,25
Zn	0,286	0,748	0,38	0,367	0,900	0,41	0,105	0,231	0,46	0,203	3,240	0,062
Ti	0,043	0,064	0,67	0,073	0,181	0,40	0,105	0,145	0,72	0,051	0,097	0,53
Σ	115,83	218,80		135,30	369,98		34,64	53,69		50,12	585,20	
Amount of Precipitation, mm	1,0	Slight Rain		0,0	Rain		0,0	Slight Rain		2,0	Rain	
Wind Velocity, m/sec	3,4			1,2			1,0			1,1		
Wind Direction	SE			W			W			W		

Table 4 (Cont'd)

Element	31 V—1 VI 1962			27—28 VI 1963			3—4 IX 1963			$\sum \frac{b}{bf}$	$\overline{\frac{b}{bf}}$
	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$	b	bf	$\frac{b}{bf}$		
Al	33,8	75,2	0,45	19,03	127,7	0,149	25,01	74,20	0,34	6,82	0,62
Mg	11,75	20,65	0,57	3,17	20,3	0,156	2,50	6,96	0,36	6,437	0,59
Ca	37,60	65,70	0,57	7,94	58,0	0,136	19,20	85,90	0,22	7,22	0,66
Fe	63,90	139,2	0,46	13,63	107,4	0,126	26,00	120,7	0,22	6,39	0,58
Mn	0,141	0,376	0,38	0,064	0,406	0,157	0,046	0,464	0,099	6,25	0,57
Ni	0,094	0,188	0,50	0,032	0,406	0,078	0,069	0,464	0,148	8,60	0,78
Cr	0,094	0,188	0,50	0,032	0,406	0,078	0,046	0,232	0,198	7,59	0,69
Cu	0,094	0,169	0,56	0,095	0,406	0,233	0,160	0,813	0,196	6,57	0,60
Pb	0,019	0,056	0,34	0,016	0,020	0,800	0,005	0,023	0,22	14,13	1,28
Zn	0,658	1,128	0,58	0,795	4,060	0,195	0,365	1,390	0,26	8,97	0,90
Ti	2,820	4,700	0,60	0,016	0,122	0,131	0,027	0,046	0,59	7,50	0,68
Σ	150,97	307,56		44,89	204,29		70,93	291,19		Average	0,64
Amount of Precipitation, mm	1,0	Slight Rain		0,0	Slight Rain		—	Fog			
Wind Velocity, m/sec	1,0			5,0			3,0				
Wind Direction	S			WNW			S				

A similar picture was observed in the case of precipitation of snow on the surface of the board (sample of 30-31 July 1962). In this case as well, for the majority of elements the ratio $\frac{b}{bf}$ 1. Exceptions were Pb, Ni, Cr, Ti, for which $\frac{b}{bf} > 1$, and Zn, for which $\frac{b}{bf} < 1$. In the sample of 16-17 May 1962, no Zn was detected.

These exceptions are apparently the result of, on the one hand, the spottiness (irregularity) of the precipitation, an uneven distribution of microconcentrations of these elements in the sample, and on the other hand, the result of a certain instability of the seizing properties of the receiving surfaces of the boards, dependent on a variety of meteorological phenomena observed during the period of exposure. The ratio $\frac{b}{bf} > 1$ is characteristic only of those elements whose relative concentration in the sample is low, i.e., comparable to the threshold values for the given method.

One of the disadvantages of iron boards is the fact that the enamel coating them deteriorates with time, so that a large amount of iron may enter the samples. Indeed, in samples collected on days without precipitation, the Fe content was minimal, but it rose sharply on days with precipitation. For this reason, in the board samples the Fe content does not correspond to the actual content in the sum of the collected aerosols. The FVA used are free from this disadvantage.

No clear-cut dependence of the amount of any particular element on the wind direction was observed. It may be mentioned, however, that in the samples of 21-22, 26-27 May 1962 and 27-28 June 1963, collected in the presence of a western wind direction, there was considerably more Al, Ca, Fe, and Mn than in the samples for 5-7 and 19-21 May 1962, collected in the presence of a southeastern wind. At the same time, a small amount of Zn is observed in samples collected in the presence of both western and southern wind directions.

Because of the small number of measurements it is still difficult to tell whether definite pollution sources exist in the region of sampling, but the potentialities of the method are such that a substantial increase in the concentration of any element can be readily determined.

The effectiveness of collection ($k = \frac{b}{bf}$) of various elements by means of a board relative to a board with flanged edges (Table 4) is characterized by a great variety of k values. If the average values for each of the elements are considered, they all, with the exception of Pb and Zn, are rather close to each other. An increase of the wind velocity in the absence of precipitation sharply decreases the ratio $\frac{b}{bf}$ for both the total elements and each individual element (samples for 5-7 May 1962 and 3-4 September 1963).

The relative mean square deviation k from the mean (0.64) is ±11%. For Pb and Zn, the deviations from the average obtained are maximum and amount to 100 and 40.5% respectively. The coefficient k for the inorganic fraction of dust, found earlier in [3] and equal to 0.60-0.67, is in good agreement with k obtained from the data of spectral analysis, for the sum of the elements and for each individual element.

If cases with abnormally high k values are excluded, the average values of k_{Pb} and k_{Zn} become respectively equal to 0.44 and 0.52, which is substantially close to the average. These anomalies are obviously due to errors in the measurement of microconcentrations of the elements, close to the threshold values for the given method.

The observed constancy of $\bar{k}$ for all the elements constitutes evidence that the different form of the board and board with flanged edges causes no distortions in the relative distribution of the elements in the samples. Therefore, it is sufficient to consider the effectiveness of (b) relative to (bf) in order to obtain comparable results of observations for both the total elements and for each individual element.

Thus, all the data on the dependence of k for each element and for the total elements on the associated meteorological phenomena for the period of collection are in good agreement with the results obtained earlier for the inorganic fraction of dust [3]. It may be stated that information on the relative distribution of elements in the samples in combination with data on meteorological phenomena can be used for identifying the sources of contamination as well as for the study of diffusion from an individual source surrounded by other sources if the element used as the tracer is correctly chosen.

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SANITARY EVALUATION OF AIR POLLUTION IN AREAS AROUND FERROUS METALLURGICAL PLANTS

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From Ministerstvo Zdravookhraneniya RSFSR, Moskovskiy Nauchno-Issledovatel'skiy Institut Gigieny im. F. F. Erismana. Voprosy gigieny, planirovki i sanitarnoy okhrany atmosfernogo vozdukha - Uchenyye Zapiski. Moscow, p. 141-147, (1966).

The accelerated growth of the ferrous metallurgical industry has drawn attention to the problem of protection of atmospheric air from industrial pollution, since the technological processes of metal production are associated with substantial discharges of waste gases and dust whose complete purification is not fully achieved. In addition, the plants are frequently located close to residential areas without a sanitary protective zone.

In this connection, the present study aimed at a comprehensive investigation of the intensity of air pollution with industrial discharges, and the elucidation of their influence on the health of the population living in areas around ferrous metallurgical plants. On the basis of the data obtained, sanitary recommendations aimed at improving the quality of the environment are given.

The studies of atmospheric air pollution by technological wastes and of the range of their propagation were conducted in areas of four metallurgical plants.

To determine the maximum atmospheric pollution, the samples were taken on the leeward side of the plants, at points where the plume produced by the smoke stacks touched the ground.

The air was analyzed for the content of sulfur dioxide, phenol, carbon monoxide, nitrogen oxides, hydrogen sulfide, ammonia, benzene, and dust. In all, 2000 samples were analyzed.

The highest intensity of sulfur dioxide was determined at distances of 3000 m from the sources of discharges. The maximum concentration originating from Plant No. 1 was 13 times the maximum permissible value, from No. 2, 5 times, and from No. 4, 3 times.

The heavy sulfur dioxide pollution of the air reservoir around plant No. 1 is explained by the fact that the raw material used consisted of ores containing up to 5% sulfur, and that the industrial gases with a high sulfur dioxide content were dumped into the atmosphere through a 60-meter stack without preliminary purification. The permissible sulfur dioxide content in the area of this plant was recorded only at a distance of 10,000 m.

Analyses of the air for phenol around 3 plants showed a particularly troublesome situation in the area of plant No. 1, where at a distance of 500-1000 m the phenol content of air exceeded the maximum permissible concentrations. A decrease of the concentrations was noted, in the successive zones, but even at the distance of 10,000 m the phenol content of air was twice the permissible norm (0.01 mg/m^3).

The pollution of air with phenol takes place as a result of the use of phenol waste waters for quenching the coke at the plants. Occasionally, the phenol content of the water reaches 250-400 mg/l, as was the case at plant No. 1. At plants No. 2 and 3, where the quenching of the coke is done by using water with a phenol content of no more than 150 mg/l, the pollution of air with phenol around the plants is much less, but still high as compared with the permissible norm.

Analyses of air for carbon monoxide around three plants (No. 2, 3 and 4) showed the heaviest pollution to occur in the zones closest to the plants, 500-1000 m.

The observed concentrations exceeded the maximum permissible value. In the subsequent zones, a decrease of the carbon monoxide content of air was observed, but in the 5000-meter zone the CO concentrations increased again. This up-and-down character of air pollution as a function of the distances may be explained by the fact that in the closest zones the intensity of pollution is due to the unorganized leakage of CO from the network of gas conduits, whereas in the more distant zones the increase of carbon monoxide concentrations is caused by the organized discharges from the smokestacks of the plant.

In a study of air pollution around 4 plants, high concentrations of nitrogen oxides were observed. The highest concentrations were found at a distance of 3000 m. A particularly heavy pollution was noted in the area of plants No. 2 (93.6 mg/m^3) and No. 4 (46.3 mg/m^3). This large amount of nitrogen oxides around these plants is thought to be due to the discharges of electric melting furnaces.

A high hydrogen sulfide pollution of air was found around three plants (Nos. 1, 2, 3). In the zone of 1000 m from plant No. 2, the peak concentrations exceeded the maximum permissible concentration. In the subsequent zones a decrease of the concentrations was observed, but even at a distance of 7000 m, the highest concentrations exceeded the maximum permissible concentration. The spread of pollution of the air reservoir with hydrogen sulfide, originating from plant No. 1, extended to 10,000 m, the maximum permissible concentration being exceeded by a factor of 7.

Analyses of air for dust content were carried out in areas of plants No. 1 and No. 4. A higher dust content was observed in the area of plant No. 1, with maximum concentrations of 5.7 mg/m^3 in the zone of 5000 m. The maximum dust content of air produced by plant No. 4 was observed in the

1000- and 3000-meter zones (2.83-2.58 mg/m^3); in the subsequent zones, the dust concentrations dropped, and at a distance of 7000 m reached the permissible value.

In addition, air was analyzed for the content of benzene and ammonia. Both of these substances were found to contaminate atmospheric air at distances up to 10,000 m. However, the benzene concentrations did not exceed the maximum permissible concentration. The ammonia concentrations found reached the relatively high value of 0.3 to 8.0 mg/m^3. It is not possible to give a hygienic evaluation of the pollution of air with ammonia because of the lack of maximum permissible concentrations in atmospheric air for this compound.

The studies showed a high intensity of pollution of atmospheric air in areas around the ferrous metallurgical plants with a number of toxic substances present in the industrial waste of the plants.

Particularly high concentrations of pollutants were recorded in the area of plants No. 1 and 2, and this was used as the basis for conducting a study of the specific influence of industrial discharges on the sanitary living conditions and health of the population residing in the vicinity of these plants.

Accordingly, in the area of plant No. 2, a survey of the population was carried out at various distances from the plants. The survey showed that the industrial discharges of the plant had an adverse effect on the well-being and the sanitary living conditions of the population. The majority of people questioned complained of the unpleasant odor of the gases carried in by the wind from the metallurgical plant. There were cases of cough, headache and difficult breathing. The effect of the gases increases during cloudy weather and particularly in autumn.

To study the influence of industrial discharges on the health of the population, comprehensive medical survey was conducted on school children 8-11 years of age living in two neighborhoods with different intensities of pollution by industrial discharges of plant No. 1. The main settlement with the heaviest and constant air pollution was located at a distance of 1000 m from the source of discharges, and the control settlement with relatively clean air was located at a distance of 12,000 m.

The medical survey of the school children involved the use of anthropometric, clinical x-ray, biochemical, clinical laboratory, physiological, and other methods of investigation.

In all, 768 persons were studied. In age, sex, and quantitative composition, the groups of children studied were similar in the two areas.

A comparative evaluation of the groups revealed a significant lag in the physical development of children in the main settlement, i.e., in growth, weight, and circumference of the chest.

Analysis of the comprehensive medical survey shows a clear-cut prevalence of diseases of the upper respiratory tract in school children of the gas-polluted area, with a frequency 3 times as high as in the control area.

In children of the main settlement as compared with the control, an ear-nose-and-throat survey revealed the greatest injury to the respiratory tract by chronic inflamatory diseases: 5 times greater with diseases of the larynx, 3 times greater with tonsillitis, 2.5 times greater with hypertrophic rhinitis, and 3 times greater with atrophic rhinitis, rhinitis and adenoids.

Data of a neurological survey of the children showed that among those from the gas-polluted area there were twice as many complaints of headache, nausea, epigastric pain and dizziness. The prevalence of functional disturbances of the central nervous system, increased fatigue and excitability, and weakening of the muscle strength were noted in this group.

Biochemical analyses on children of the main settlement showed the presence of sulfur dioxide in the blood, ranging from traces to 0.12 mg%. Under normal conditions, no sulfur dioxide should be present in the blood. SO_2 appears in the blood only when the air is heavily and constantly polluted with it.

The presence of sulfur dioxide in the blood of children has an adverse effect on the body and on its defensive functions. This is confirmed by the amount of vitamin C in the blood and the extent of its elimination from the body with urine.

The amount of vitamin C eliminated with urine in school children of the main group was half as much as in children of the control group. The study established that in many cases, small amounts of vitamin C in urine correspond to an increased content of sulfur dioxide in the blood. Thus, in the case of schoolgirl K., the sulfur dioxide content of the blood was 0.12 mg%, and the amount of vitamin C in the urine, 0.08 mg/hr. In the case of schoolboy G., traces of sulfur dioxide were found in the blood, and the amount of vitamin C eliminated with urine rose to 0.47 mg/hr.

The action of high concentrations of toxic substances present in atmospheric air decreases the biological resistance of the child's body, reduces its defensive properties, and predisposes to infectious diseases and to illnesses such as colds, etc.

The identified hemolytic shifts in children of the main area correlate to some degree with the above indicated prevalence of inflammatory diseases of the upper respiratory tract in this group as compared with the control group.

The data of the City Public Health Department show that the disease rate among children of the main area for 1962 was higher than in the control area.

The data of the medical survey coincide with the disease rate indices of this department.

Comparison of the results of the medical survey of selected groups of school children in the two neighborhoods made it possible to establish a relationship between these data and the intensity of pollution of atmospheric air with industrial discharges of plant No. 1.

The study showed a high intensity of pollution of atmospheric air with industrial discharges of ferrous metallurgical plants, extending to a distance of 7000-10,000 m from these plants and having an adverse influence on the sanitary living conditions of the population.

Children living in the sanitary protective zone (1000 m) of plant No. 1 suffer from chronic diseases of the upper respiratory tract, and somatic and infectious diseases much more frequently than children living at a distance of 12,000 m from the plant.

In the course of the study, each plant was given recommendations for improving the environment.

Research on the biological effects of industrial discharges of ferrous metallurgical plants is continuing.

SANITARY EVALUATION OF AIR POLLUTION AROUND FERROUS METALLURGICAL PLANTS

A. P. Makhinya

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Among the many industrial enterprises contaminating the air of populated areas with their industrial discharges, an important part is played by ferrous metallurgical plants.

At the present time, for economic reasons, plants of the by-product coke industry are constructed near metallurgical plants.

Coke-chemical plants discharge the most varied chemical substances into the atmosphere: sulfur dioxide, phenols, hydrogen sulfide, naphthalene, cyanide compounds, benzene, hydrocarbons, dust, soot, and other compounds.

Thus, the Magnitogorsk metallurgical complex dumps daily over 0.5 billion m^3 of polluted gases into the atmosphere. At a distance of 3500-5000 m from the complex, sulfur dioxide concentrations were observed which exceeded the maximum permissible value by a factor of 3 or more. In 1958, Ye. V. Yelfimova observed that the maximum single concentrations of sulfur dioxide at a distance of 1000-7000 m exceeded the maximum permissible value by factors of 25-3.8.

In the area of the Kemerovo coke-chemical plant, maximum single phenol concentrations equal to 0.04-0.97 mg/m^3 were observed (A. A. Itskovich, 1955).

According to the data of the Sverdlovsk Scientific Research Institute of Labor Hygiene and Professional Diseases (1950), which conducted a survey of atmospheric air around a coke-chemical complex and a gas plant within a 3 km radius, the maximum single phenol concentration at a distance of 500-1000 meters was found to be 3.143 mg/m^3, at a distance of 2000 m, 0.989 mg/m^3, and in the 3000 m zone, 1.096 mg/m^3.

We studied the air in zones around enterprises including coke-chemical plants, which constitute the chief source of air pollution.

Two metallurgical plants were selected for the study. These were two enterprises of different capacities located under differing natural and climatic conditions and operating on different raw materials.

The survey was made according to seasons (summer, autumn).

The first metallurgical plant is located in an open, level area containing water reservoirs, marshes and forest tracts, which made it relatively inaccessible to the study of atmospheric air at a distance of more than 7000 m.

Around this area, the air samples were taken during the month of July at a temperature of the surrounding air between 25 and 30°C. at a wind velocity from 0 to 3 m/sec, and at a moderate relative humidity (39-62%).

Under such conditions, the maximum single concentrations are somewhat low, since they reach their highest values during unfavorable combinations of meteorological factors.

Nevertheless, the phenol concentrations, even at a distance of 3 km from the sources of discharge, exceeded the maximum permissible value (0.01 mg/m^3) by a factor of 10-13 (Table 2). The sulfur dioxide concentrations obtained around the Cherepovets metallurgical plant are listed in Table 1.

It is apparent from the table that at a distance of 500 m the sulfur dioxide concentrations exceed the maximum permissible value by a factor of 1.6-1.2, in the 1000 m zone the maximum single concentration exceeds the maximum permissible value by a factor of 1.4, and the average concentration is below the maximum permissible level. In all the subsequent zones (3000-5000-7000 m), the indices studied were found to be considerably below the maximum permissible concentration.

Table 1

Sulfur Dioxide Concentrations in Zones Around the First Metallurgical Plant, mg/m^3.

Distance From Source of Discharge m	Number of Samples	Maximum Concentration	Average Concentration	Excess over MPC
500	20	0,88	0,6	By a Factor of 1.6-1.2
1000	20	0,70	0,4	By a Factor of 1.4 and < MPC
3000	20	0,09	0,06	< MPC
5000	20	0,06	0,02	< MPC
7000	12	0,02	0,01	< MPC

The indices of air pollution with phenol around the first metallurgical plant are listed in Table 2. It is evident that the phenol concentrations at a distance of 500 m from the points of discharge exceed the maximum permissible value by a factor of 30-38, and in the 1000 m zone, by a factor of 20-28. No phenol could be observed at a distance of 5000 m from the sources of discharge.

Table 2

Phenol Concentrations in the Zones Around the First Metallurgical Plant, mg/m^3.

Distance From Source of Discharge, m	Number of Samples	Maximum Concentration	Average Concentration
500	20	0,38	0,3
1000	20	0,28	0,2
3000	20	0,13	0,08
5000	16	0	0
7000	8	0	0

At this plant, the phenol waters are purified by means of a bioculture, and this obviously had a positive effect on the phenol concentrations in the surrounding atmospheric air.

The population of the city, living at a distance of up to 7 km from the plant, complains of an unpleasant, irritating odor of the gases, so that it is impossible to air out the dwellings or to open the air vents while sleeping.

The rural population living at a distance of 7 or more kilometers from the plant also complains of an unpleasant odor of the air, which causes a cough, hinders breathing, and is particularly bothersome during the autumn period of the year, since in humid weather the smoke produced by the plant almost creeps on the ground.

The study of air pollution in the zones around the second metallurgical plant was made in September-October 1963. In this case also, single samples were collected under the plume at various distances from the main sources of discharge, the coke chemical plant being taken as the "epicenter".

From the data obtained, listed in Table 3, it is evident that the maximum permissible concentration of sulfur dioxide is exceeded at a distance up to 3000 m, and that of phenol, up to 5000 m.

Table 3

Sulfur Dioxide Concentration in the Zones Around the Second Metallurgical Plant, mg/m^3.

Distance From Source of Discharge, m	Number of Samples	Maximum Concentration	Average Concentration	Excess over MPC
500	20	0,80	0,41	1.6 times
1000	20	0,45	0,21	< MPC
3000	20	2,6	1,9	5.2-3.8 times
5000	20	0,4	0,3	< MPC
7000	20	0,1	0,05	< MPC

The highest sulfur dioxide concentrations were observed in the three-kilometer zone (residential area) where the maximum single permissible concentration was exceeded by a factor of 5.2-3.8 times. The air samples were collected at a temperature of 10°C., humidity of 74%, and wind velocity of 3 m/sec. A strong and steady odor of sulfur dioxide was noted at a distance of 500 m. The maximum single concentrations exceeded the maximum permissible value by a factor of 1.6. In all the remaining zones (1000, 5000, 7000 m), the sulfur dioxide content of the samples was considerably below the level of the maximum permissible concentration.

Table 4

Phenol Concentration in the Zones of the Second Metallurgical Plant, mg/m^3.

Distance From Source of Discharge, m	Number of Samples	Maximum Concentration	Average Concentration
500	20	0,18	0,10
1000	20	0,35	0,20
3000	20	0,18	0,07
5000	20	0,035	0,02

The phenol concentrations in the zones around the second metallurgical plant are shown in Table 4. At a distance of 500 m they exceed the level of the maximum permissible value (0.01 mg/m^3) by a factor of 10, and at a distance of 5000 m, by a factor of 3.5-2, i.e., they approach the maximum permissible concentration.

It should be noted that in the evening and at night, the gas odor is stronger in the city than during the day, since in the evening and at night, the plume spreads closer to the earth's surface, and during the day, the opposite takes place.

A gradual destruction of a pine forest located at a distance of 7 km from the discharges of the second metallurgical plant was observed.

To elucidate the influence of discharges of the complex on the sanitary living conditions and well-being of urban dwellers, a survey was made among the population living at various distances from the second metallurgical plant. In all, 372 people were questioned.

The majority of the persons questioned note that the metallurgical plant is a massive source of air pollution with noxious, malodorous gases that disturb them all year round. A considerable number of those questioned complained of dust in the eyes, difficult breathing, headache, and cough. Many complained of laundry being dirtied while drying and of their inability to open the windows and air vents because of the unpleasant odor and large amount of dust.

The results of the studies established that ferrous metallurgical enterprises constitute definite sources of pollution of atmospheric air with sulfur dioxide, phenol, and other noxious substances and that special steps must be taken to protect this air.

The solution of this problem should be pursued along the lines of further improvement of the technological processes and equipment.

The data of the analyses and survey of the population lead to the conclusion that the existing sanitary protective zone of 1000 m (SNiP-PMI-62) for plants of such capacity is insufficient and should be reviewed so as to be enlarged.

The present study will be continued under experimental conditions for the purpose of studying the biological effect of sulfur dioxide and phenol on the human and animal organism, so that there will be a sanitary basis for establishing maximum permissible concentrations of combinations of these substances in atmospheric air.

EXPERIMENT IN THE USE OF A HELICOPTER FOR A HYGIENIC STUDY OF THE DYNAMICS OF AIR POLLUTION

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In a comprehensive study made in 1960-1963 on the factors affecting the intensity of atmospheric dispersal and range of propagation of gases and ash discharged by the stacks of a high capacity thermal electric power plant, several measurements of sulfur content were made in the smoke cloud itself with the aid of a helicopter.

The reconnaissance flight made it possible to determine the feasibility and conditions for such a study and served as the basis for the development of an appropriate method.

Two aspirators designed by the engineer L. F. Kachor, mounted in the cabin, were connected in series to the helicopter's power supply system. The air samples were collected simultaneously into four V-shaped absorbers. Rubber tubes whose opposite ends were inserted in the window of the helicopter's cabin were slipped on the suction nozzle of all the absorbers. The air was taken from the space around the helicopter, subjected to the constant action of 6-meter rotor blades rotating in the horizontal plane at a height of 4 meters above the point of sample collection. The downward air stream insured a homogeneous mixing of the smoke cloud in the zone where the helicopter was located.

In view of the fact that, while hovering, the K-18 helicopter continues to execute a slow rotary-forward motion, the air samples were collected at the minimum velocity of intersection of the plume for the purpose of exposing the sampling in accordance with the method of colorimetric determination of sulfur dioxide which is recommended by the Committee on Sanitary Protection of Atmospheric Air.

Thus, the collected sample was not strictly axial, since it recorded the average gas content of atmospheric air in the cross section of the plume at each studied distance from the source of discharges.

The distances studied were: 2 km (because of the saturation of air with the gases, the helicopter could not come closer to the stacks of the SREPP), 3, 5, and 10 km. When the helicopter flew in a straight line across the plume, the width of the plume was determined visually from the instant of "fogging" (entry into the smoke cloud) in accordance with the zones studied; this width was found to be 200-1000 m.

The experiment was conducted on 9 August 1962 between 5 and 6 P.M. under the following weather conditions: visibility up to 15 km, negligible cloudiness of the middle levels (altocumulus clouds), air temperature 27.5°C., wind velocity at the height of the vane 5 m/sec, direction of the wind west-southwest. The visible plume, in a wide-open fan shape, rose slightly up to 2 km and then, descending somewhat, ran almost parallel to the surface of the ground.

The operating conditions of the SREPP during the period of the experiment were characterized by the following indices: fuel consumption 634.4 t/hr, total discharge of exhaust gases around 3,350,000 nm^3/hr, average temperature of waste gases +159°C.

The results of the experiment are presented in Table 1.

The data cited show that a washing out of the impurity concentrations in the plume with increasing distance from the source takes place rapidly: at 2 km, 3.5 mg/m^3; 5 km, 1.20 mg/m^3; 10 km, 0.20 mg/m^3, and at the 10 km distance the gas content of the plume was below the permissible sanitary value for the atmospheric air of populated areas at man's breathing level.

Table 1

Distribution of Sulfur Dioxide Concentration in a Smoke Plume at Various Distances from the SREPP.

Distance From Stacks, km	Height From Base of Stacks, m	Concentration, mg/m^3		
		Maximum	Average	Minimum
2	680	3,50	2,23	1,40
3	580	1,96	1,69	1,56
5	580	1,20	0,80	0,44
10	580	0,20	0,20	0,20

To evaluate the influence of the dispersal of the smoke plume on the pollution of atmospheric air in the ground layer, simultaneously with the helicopter studies, air samples were collected under the plume and analyzed for the sulfur dioxide content synchronously in the following zones: 1, 2, 3, 4, 5 and 10 km. In each zone, two or a maximum of three samples were collected simultaneously. The gas content was determined by the same chemical method.

The data obtained are listed in Table 2.

The distribution of maximum single concentrations between 5 and 6 P.M. on 9 August shows a zone of high sulfur dioxide content located between 2 and 4 km (maximum 1.32 mg/m^3 - 1 sample).*

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*The calculated maximum value based on P. I. Andreyev's formula was 1.88 mg/m^3, and the calculated value based on the "Time-Dependent Method" was 1.07 mg/m^3.

Starting at 5 km, the gas content of atmospheric air in man's breathing zone turned out to be below the maximum permissible single concentration of 0.5 mg/m^3.

Table 2

Distribution of Maximum Single Concentrations of Sulfur Dioxide in the Ground Layer of the Atmosphere in the Region of the SREPP.

Distance From Source of Discharge, km	Number of Samples	Concentrations, mg/m^3			
		Maximum	Average of Maxima	Minimum	Above MPC
1.0	4	0,08	0,075	0,06	—
2.0	9	1,32	0,93	0,31	7
3.0	6	0,63	0,43	0,16	3
4.0	9	0,68	0,31	0,16	2
5.0	6	0,22	0,14	0,08	—
10.0	4	0,28	0,14	0,05	—

A graphic representation (Fig. 1) of the intensity of the sulfur content and dynamics of propagation of sulfur dioxide in the plume of the discharge and in the ground layer of the atmosphere shows that when the concentrations reach 7.5 mg/m^3 near the outlets of the stacks (interpolation data) the maximum values at the base at a distance of 1000 m do not exceed 0.08 mg/m^3. As the smoke cloud moves on, the opening of the angle of the plume in the vertical plane causes the sulfur content of the plume to decrease, but at the same time raises the gas content of atmospheric air in the ground layer. At large distances around 10 km, the sulfur dioxide content of atmospheric air is rather uniform both high in the air (580 m) and in man's breathing zone.

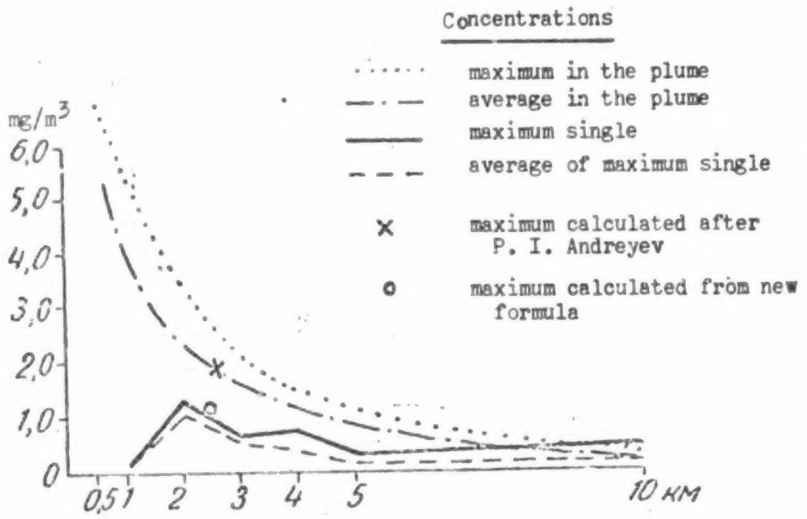

Fig. 1. Interdependence of sulfur dioxide concentrations in the plume and in the ground layer of atmospheric air at various distances from stacks of the SREPP.

NEW METHOD OF CALCULATING THE DISPERSAL OF DISCHARGES FROM THERMAL ELECTRIC POWER PLANTS IN ATMOSPHERIC AIR AND ITS SANITARY EVALUATION

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In the struggle with the industrial air pollution of populated areas, high smokestacks assume an urgent importance in cases where it is technically impossible at the present time to eliminate the discharges or reduce their content of pollutants.

Other things being equal, the degree of gas and dust pollution of the ground layer of the atmosphere in the area of an operating organized source of discharges is always inversely proportional to the height of the discharging stack.

The stack gases are dispersed in the surrounding air and transported along with it, and for this reason, in addition to the height, capacity, and chemical nature of the discharge, the weather conditions play an essential part in the dispersal of noxious impurities in the atmosphere. We shall cite an example based on two sets of measurements of sulfur dioxide concentrations in atmospheric air, carried out at the same hours, but on different days, within a 3-kilometer zone around 120-meter stacks of an SREPP operating on Moscow coal. From the diagram (Fig. 1) it follows that a discrepancy of the sulfur dioxide concentrations determined at one and the same point is chiefly due to a marked change of the wind velocity. The high wind velocity of 14 March, 20 m/sec, caused the plume to cling to the earth's surface; this was also promoted by a snowfall. On 24 March during a slight wind of 4 m/sec, the plume remained high, causing a marked decrease in the maximum sulfur dioxide concentrations. Pollutants discharged into the air by high-capacity and high sources may spread in the atmosphere along the direction of the wind to great distances (in the area of the SREPP studied, 40 and more kilometers).

The chief meteorological factors affecting the dispersal are, in addition to the wind velocity, the vertical and horizontal exchanges in the atmosphere, i.e., its turbulent state.

An appropriate consideration of the physical processes of the atmosphere permits a specific determination, in each region of the country, of the permissible amount of a noxious substance in a discharge for a given height of the smokestack, or the required stack height for a known volume of waste gases and their quantitative content of impurities. An appropriate consideration of the meteorological factors permits a valid solution of the problem of the necessary size of the sanitary protective zone.

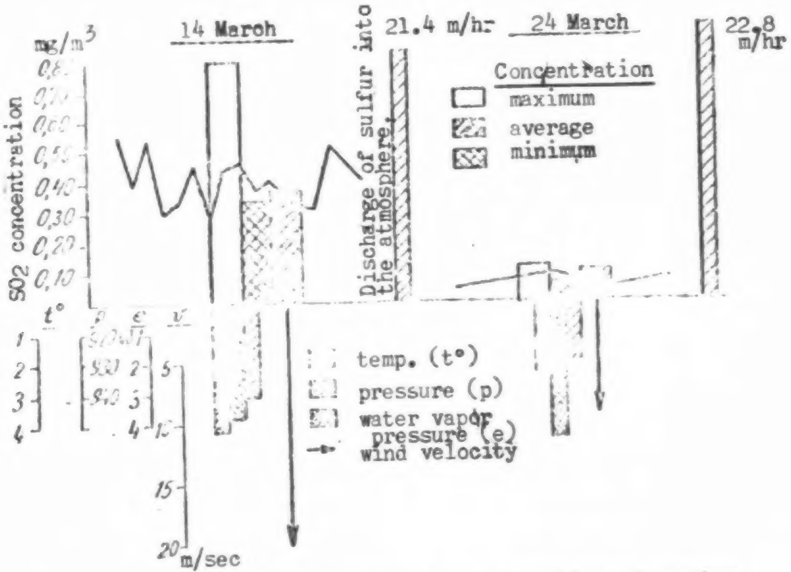

Fig. 1. Intensity of air pollution as a function of weather conditions.

Several formulas by Soviet and foreign authors proposed for the determination of probable atmospheric air pollution by dust and gases are known: those of G. V. Sheleykhovskiy, S. A. Klyugin, P. I. Andreyev, N. F. Dergachev, Bozanke, Davidson, Holland, and others. These formulas are empirical in character and the data obtained from calculations based on them seldom agree with the materials of field studies. P. I. Andreyev's formula, which best reflects the actual air pollution in the effective range of an organized industrial source of discharges, has been adopted most widely in the practice of planning organizations and sanitation departments of the USSR. The main difference in these formulas is the approach to the determination of the dynamic height of the discharge. Thus, whereas the calculation by Andreyev's formula gives the dynamic height of the discharge of a high capacity SREPP as 50 m, Dergachev's formula gives 90 m, Holland's formula for the same conditions gives a height of the order of 160 m, and Bozanke's formula gives as much as 250 m. The marked discrepancy of the calculated indices of the dynamic height in the determination of the effective height is partly because Andreyev's and Dergachev's formulas do not consider the additional rise of the gas stream as a result of the difference in the temperatures of the surrounding air and of the hot waste gases of the SREPP. On the initiative of the Erisman Institute, an additional reducing coefficient of 3.0 was introduced into Andreyev's formula for the calculation of the maximum sulfur dioxide concentration in atmospheric air on the basis of a comparison of calculated data and actual pollution in the area of several thermal electric power plants.

Field studies in the area of a high capacity SREPP in 1960-1962 showed that the conditions producing any given elevation of the gaseous stream jet largely depend on the turbulent structure of the atmosphere and therefore are not a constant quantity and cannot enter into the dispersal formula as an unchanging integral part (for a constant wind velocity).

Comprehensive three-year studies in the area of a high capacity SREPP with a sufficiently complete synchronous recording of the meteorological indices, including lapse rate observations, regime factors of the operation of the electric power plant, and quantitative content of dust and sulfur dioxide in the ground layer of atmospheric air, enabled the A. I. Voyeykov Main Geophysical Observatory (MGO) to derive a new formula, based on the theory of turbulent diffusion, for the calculation of the dispersal of gases and dust for the discharge conditions of high-capacity thermal electric power plants:*

$$C_m = \frac{AMFm}{H^2}\sqrt[3]{\frac{N}{V\Delta T}},$$

where C_m is the maximum concentration of the pollutant at man's breathing level (1.5-1.8 m) in mg/m^3;

A is a coefficient dependent on the temperature stratification of the atmosphere, defining the conditions of vertical and horizontal dispersal of the impurity in air. Coefficient A is taken for unfavorable conditions, when the wind velocity (U_m) reaches the unsafe value $U_m = 0.65 \times \sqrt[3]{\frac{V\Delta T}{NH}}$ (for high capacity thermal electric power plants U_m = 5-7 m/sec) and an intense vertical exchange takes place during which the ground concentration reaches its maximum value. For Kazakhstan, Central Asia and the central part of Siberia, the value taken is A = 200. For the north and northwest of the European territory of the USSR, the Ural and Ukraine, A = 160. For the central portion of the European territory of the USSR and in areas with similar climatic conditions A = 120;

M is the total discharge of pollutant per second from all equally high smokestacks expressed in grams (g/sec).

F is a coefficient allowing for the settling rate of the dust particles. For a mean operational coefficient of ash trapping above 90%, F = 2.0, and below 90%, F = 2.5.

m is a coefficient dependent on the exit velocity of the gases at the mouth of the stack (W_0); the values of m are given in Table 1.

Table 1

Values of m at Various Exit Velocities of Gases Discharged From the Mouth of a Smokestack.

W_0, m/sec	10—15	20—25	30—35
m	1,0	0,9	0,8

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*See "Sanitary Evaluation of Atmospheric Air Pollution in the Area of a High Capacity Thermal Electric Power Plant" by the same authors.

H is the geometric height of the smokestack in meters (m);
N is the number of stacks of the same height and same mouth diameter;
V is the total volume of stack gases discharged per second (m^3/sec);
ΔT is the difference between the temperature of the gases leaving the stack (T_g) and the temperature of the ambient air (T_a).

The formula is suited for the calculation of maximum probable sulfur dioxide and dust concentrations (fly ash) in the ground layer of the atmosphere for the conditions of discharges of thermal electric power plants with $H > 50$ m; $\frac{V}{N} > 20\ m^3/sec$ and $\Delta T > 30°$. The maximum calculated impurity concentration is observed theoretically at a distance $X_m = 20H$. Field studies of air pollution in the area of the SREPP (Table 2) show that the point of determination of the maximum concentration is more correctly regarded as the zone of heaviest pollution.

Table 2

Distribution of Maximum Single Extreme Concentrations in the Zone of Heaviest Air Pollution, mg/m^3.

	Distance, km					
Pollutant	1,0	2,0	3,0	4,0	5,0	6,0
Sulfur Dioxide	3,28	2,60	3,59	3,10	2,53	4,03
Dust	1,92	2,46	4,62	3,40	3,38	2,96

Accordingly, the time-dependent method of calculation of dispersal of discharges in the atmosphere, developed by the MGO in collaboration with the Erisman Institute, was used to determine the zone of maximum concentrations from 10 to 40 H.

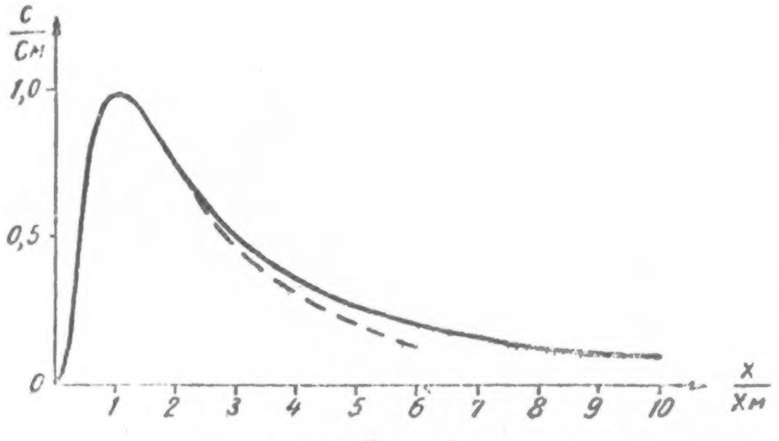

Fig. 2. Interdependence of $\frac{X}{X_m}$ and $\frac{C}{C_m}$.

The calculation of the dust and gas content at a point distant from the zone of observation of maximum concentrations, for example, at the boundary of a residential settlement, is carried out by means of a graph (Fig. 2). On this graph, the abscissa axis represents the ratio of the unknown distance (X) to the maximum distance (X_m), and the ordinate axis, the ratio of the unknown concentration (C) to the maximum concentration (C_m), determined from the basic formula. The dashed line on the graph indicates a faster decrease of the dust concentrations in air at large values of X. The correctness of the determination of probable air pollution with the aid of this graph is confirmed by the agreement between the calculated and observed data on the ratios of C at distances of 2-15 km to C_m for sulfur dioxide and at a distance of 1-6 km for dust in the presence of a dangerous wind velocity (Table 3).

Table 3

Theoretical and Experimental Values of $\frac{C}{C_m}$ for Sulfur Dioxide and Dust.

Pollutant		Distance, km						
		1,0	2,0	3,0	4,0	6,0	10,0	15,0
Sulfur Dioxide	Calculated	—	0,9	1,0	0,9	0,5	0,3	0,2
	Experimental	—	0,8	0,9	0,8	0,6	0,5	0,3
Dust	Calculated	0,4	0,9	—	0,9	0,8	—	—
	Experimental	0,5	1,0	—	0,8	0,6	—	—

In order to establish the sanitary reliability of the new method of calculation, the maximum single extreme and average extreme concentrations of sulfur dioxide and dust (fly ash), observed some time during the period of studies in 1960-1962 in the area of a high capacity SREPP, were compared with calculations made by using Andreyev's formula and a new formula for the conditions of maximum load on the electric power plant: amount of burned fuel, 18.5 thousand tons; ash content $A^P = 26.2\%$; sulfur content $S^P_{tot} = 3.0\%$; average performance coefficient of electrostatic precipitators 87%. It is evident from Fig. 3 that the sulfur dioxide concentrations (maximum 5.4 mg/m^3) calculated with Andreyev's formula by using a reducing factor of 3.0 are 1.3 times higher than the extreme concentrations (4.03 mg/m^3) based on the highest indices. Without the factor of 3.0, the maximum calculated value would be 16.2 mg/m^3. The curve of extreme concentrations was plotted on the basis of data for 36 determinations out of 7097 air samples collected at various distances from the stacks of the SREPP.

The zonal distribution of the calculated concentrations obtained with the new formula (maximum 2.81 mg/m^3) is hygienically a more correct expression of the frequently occurring true zonal gas pollution of the ground layer of the atmosphere, since even the actual concentrations averaged over 5 cycles of investigations were found to be below or at the level of the calculated values. The high gas content of the atmosphere observed at distances of 500-1000 m from the SREPP, as compared with the calculated content, is owing to the influence of low-level discharges from a small-scale production of slag wool in the vicinity of the SREPP.

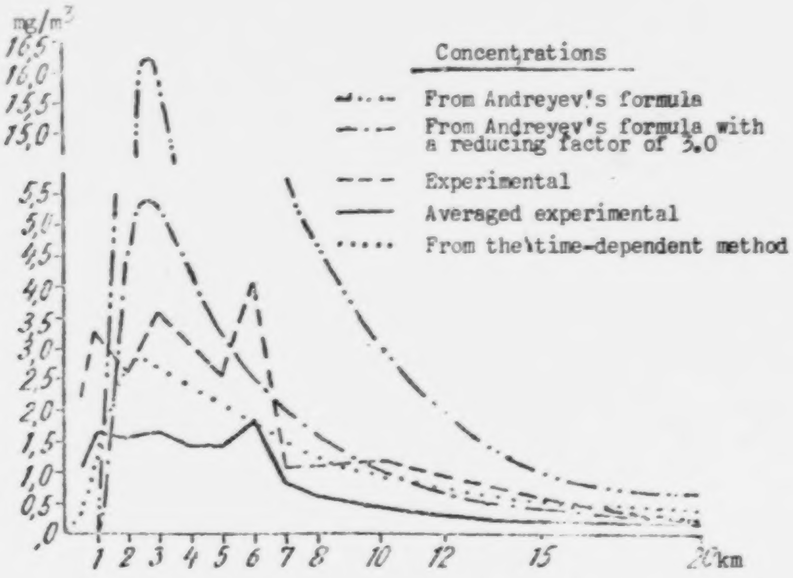

Fig. 3. Distribution of maximum concentrations of sulfur dioxide in atmospheric air in the area of a high capacity SREPP (observed and calculated data in mg/m^3).

A graphical representation of the distribution of dust concentrations (Fig. 4) clearly shows that the maximum concentration calculated with Andreyev's formula, 7.9 mg/m^3, is considerably higher (more than 1.5 times) than the extreme concentrations, whose number in all the zones studied was only 45 out of a total number of air samples of 1452. Comparison of the curves shows that the calculation using Andreyev's formula gives unjustifiably high indices of dust content in atmospheric air when the waste gases of the SREPP are discharged at a height of 120 m. The extreme values averaged over all the cycles of studies made in 1960-1962, i.e., the maximum single concentrations frequently observed (about 300 determinations), are in good agreement with the calculated concentrations obtained by the use of the new formula. The high dust content of atmospheric air in the immediate 500 m zone around the SREPP as compared with the calculated content is explained by the presence of an unorganized source of dust - a coal yard - on the industrial site, and also by the gravity settling of coarse ash particles in the vicinity of the source of discharges.

On the basis of the above, we come to the following conclusion: the use of the new formula for calculating the dispersal for the determination of the probable maximum gas and dust contents of atmospheric air in populated areas under the discharge conditions of high capacity thermal electric power plants is warranted from a sanitary-hygienic standpoint.

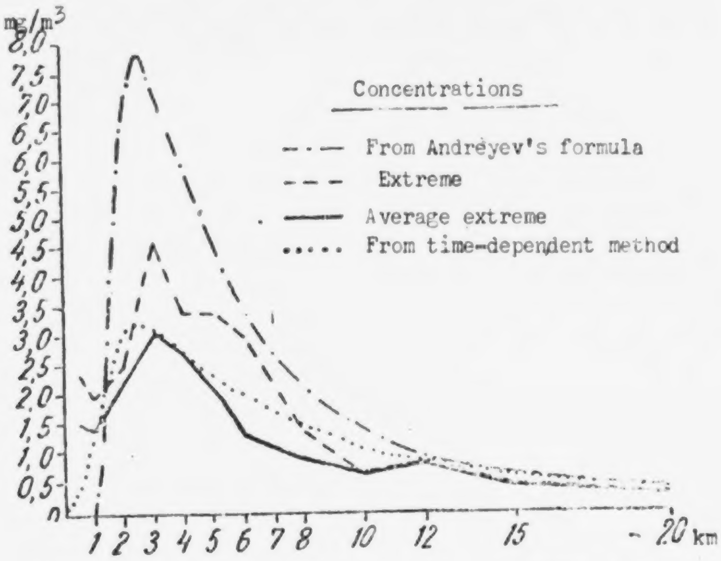

Fig. 4. Distribution of maximum dust concentrations (fly ash) in atmospheric air in the area of a high capacity SRFPP (observed and calculated values in mg/m³).

A decision of the State Committee on Coordination of Scientific Research in the USSR, No. 83, published on 25 July 1963, has approved a "Time-dependent method of calculation of atmospheric dispersal of discharges (ash and sulfur compounds) from smokestacks of electric power plants."

SANITARY EVALUATION OF ATMOSPHERIC AIR POLLUTION IN THE AREA OF A HIGH CAPACITY THERMAL ELECTRIC POWER PLANT

R. S. Gil'denskiol'd, B. V. Rikhter, and V. M. Styazhkin

(Based on data of comprehensive studies made in 1960-1963)

From Ministerstvo Zdravookhraneniya RSFSR, Moskovskiy Nauchno-Issledovatel'skiy Institut Gigieny im. F. F. Erismana. Voprosy gigieny, planirovki i sanitarnoy okhrany atmosfernogo vozdukha - Uchenyye Zapiski. Moscow, p. 117-126, (1966).

The construction of high capacity and extra-high capacity thermal electric power plants, gigantic metallurgical and chemical plants, and the creation of new cities and workers' settlements in the Soviet Union has posed the problem of reliable prediction of probable atmospheric air pollution in the zone around major industrial facilities. The determination by calculation of close-to-actual concentrations of air pollutants permits sanitary organizations, even at the planning stage, to give a sanitary-hygienic evaluation of the projected measures aimed at purifying atmospheric air in the adjoining populated areas to the level of specified maximum permissible concentrations.

The working formulas developed by Soviet and foreign authors for this purpose are empirical in character. The results of calculations made with the aid of these formulas are not in mutual agreement and seldom agree with the data of field studies of actual conditions.

In 1960, it was decided to organize as completely as possible studies of the physical state of the atmosphere under natural conditions, in order to determine the dynamics of propagation of pollutants from a large, organized source of discharges, and, on the basis of the collected material, to evaluate the existing methods of calculation of gas and dust concentrations in atmospheric air, or if necessary, to work out a new formula for calculating the dispersal of pollutants in atmospheric air. All the requirements of such a natural experiment are best met by modern thermal electric power plants operating on low-grade, high-ash and high-sulfur solid fuel with heavy discharges through high smoke stacks. The usefulness of such a choice is also emphasized by the fact that the power output of the USSR by the year 1980 should reach 2700-3000 billion kW, which will require the construction of 260 TEPP and 200 SREPP with a power up to 3 MW and smokestacks up to 250 m high.

Data obtained from earlier studies of air pollution around several electric power plants (B. P. Gurinov, M. S. Gol'dberg, N. Ya. Yanysheva, and others) could not be used as the basis for checking the uniformity of the data calculated from the existing formulas and data actually observed for three basic reasons: a) small zone of study of pollution of the air environment - no more than 5 km from the discharge source; b) simultaneous collection of air samples at no more than 3-5 points, this being obviously insufficient for following the processes of gas and dust dispersal in the atmosphere; c) lack of gradient observations - one of the key factors affecting the turbulent conditions.

The object chosen for the study was a SREPP (State Regional Electric Power Plant) with a power of 610,000 kW operating on brown coal of the Moscow basin, with an ash content of 26.2% and a sulfur content up to 3.0%. The maximum daily consumption of burned fuel in 1960-1962 reached 18.5 thousand tons with a mean hourly consumption of 700 tons. The average total discharge of ash from four 120-meter stacks was 15.0-17.0 tons/hr or 360-400 tons/day. The total discharge of sulfur dioxide in 1961 reached a maximum of 49.0 tons/hr, and in 1962, 39.4 tons/hr. In 1963, natural gas began to be partially supplied to the SREPP for combustion, and the consumption of coal was reduced to a minimum of 779 tons/day with an average of 6.8 thousand tons. At the SREPP, only ash is removed from the waste gases by means of vertical-plate electrostatic precipitators, the average efficiency of the units being 87%. The slag and ash trapped by the hydrosol removal system are transported to an ash dump located 1.5 km from the SREPP.

The following organizations took part in the general coordinated program of comprehensive studies in the area of the SREPP: A. I. Voyeykov Main Geophysical Observatory (MGO), F. E. Dzerzhinskiy All-Union Heat Engineering Institute (AHI), Southern Affilliate of the Trust for the Organization and Efficiency of Regional Electric Power Plants and Networks (SATOEREPPN) and the F. F. Erisman Scientific Research Institute of Hygiene in Moscow. The MGO team determined the physical conditions of the boundary layer of the atmosphere in the region of the SREPP during the periods of field investigations. In addition to standard meteorological observations carried out at the organized and steadily operating weather station, balance, lapse rate, and special measurements, using a captive balloon, a helicopter, and an airplane, were made. The gradient observations included the measurement of temperature and air humidity at heights of 0.25 to 16.7 m, and the measurement of wind velocity.

The balance observations included determinations of evaporation from the soil and actinometric measurements of all the balance components. Special studies made during balloon ascents furnished data on the distribution of temperature and air humidity, wind velocity, and dust content at heights from 50 to 1000 m. Similar data for heights from 100 to 1000 m were obtained by means of instruments mounted in the helicopter (vertical sections directly in the smoke plume itself). The airplane was used for a similar vertical and horizontal sounding of the boundary layer along the plume up to 40-60 km and to a height of up to 5 km. The structures of turbulent streams and the distribution of condensation nuclei were thus determined, the smoke plume was outlined and its boundaries were determined, and in addition, the microclimatic characteristics were recorded directly at the points of collection of air samples.

The AHI team recorded the sulfur content of the fuel, calculated the hourly amount of sulfur dioxide discharged during the field observations and the total daily discharge of sulfur dioxide during the entire cycle of investigations.

The SATOEREPPN team determined the amount of burned fuel, the amount of ash in the discharge of each smoke stack and the total amount discharged by the SREPP, the fractional composition of ash particles discharged into the atmosphere, the volume of waste gases, the velocity of the gases in the chimney, and their temperature.

The team of the F. F. Erisman Institute determined the maximum single concentrations of sulfur dioxide and dust (fly ash) in the ground layer of atmospheric air around the SREPP within a 20 km radius in the following zones: 0.5, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 km. The collection of air samples to be analyzed for sulfur dioxide content of atmospheric air was made with 15-20 samplers in two ways: a) simultaneous selective collection along the horizontal projection of the longitudinal axis of the smoke plume in the zones including the maximum 20 km radius. In each zone, in addition to the main point of collection taken conditionally as the center of projection of the plume axis, one or two lateral points were established at a certain distance from one another for the objective determination of the true axis of the horizontal projection of the plume. Such an arrangement of the air samplers ensured the recording of the dynamics of propagation and dispersal of sulfur dioxide in atmospheric air at a large distance and revealed the dependence of these processes on the physical state of the atmosphere; b) simultaneous collection of air samples at right angles to the horizontal projection of the longitudinal axis of the plume at various distances from the source of discharges in each consecutive zone, with a range up to 2 km. This arrangement made it possible to record the rate of washing-out of the smoke cloud in the ground layer of the atmosphere as a function of the weather conditions and to determine the boundaries of the smoke plume. The study of the dynamics of gas pollution of atmospheric air according to this program naturally has caused the number of samples with sulfur dioxide concentrations above the sensitivity limit of the methods of determination to be considerable in relation to the total number of air samples taken. The sulfur dioxide concentrations in the air samples were determined by the nephelometric and colorimetric methods recommended by the Committee on the Sanitary Protection of Atmospheric Air.

The study of the zonal spreading of fly ash under the plume was made at distances of 0.5 to 20 km from the source of discharge in each consecutive zone. The air samples were collected by means of automobile aspirators of the system developed at the Erisman Institute. The use of FPP cloth as the filtering material made it possible to determine the particle size composition of the aspirated sample.

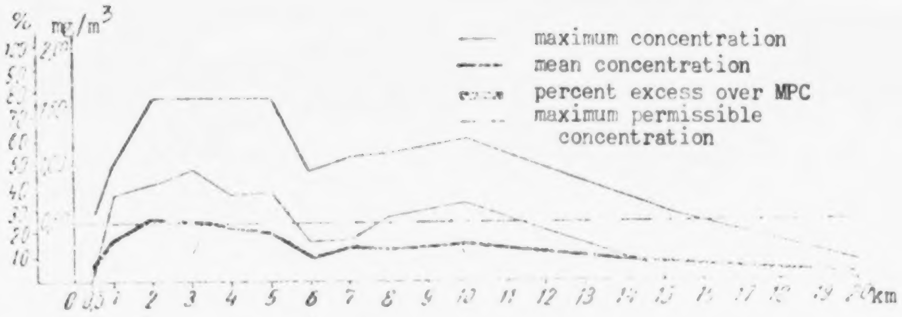

Fig. 1. Dynamics of propagation of sulfur dioxide concentration (maximum and mean maximum values) in atmospheric air within a 20 km radius of SREPP.

The total number of air samples to be analyzed for sulfur dioxide content in the region of the SREPP in 1960-1963 was 9691. The most complete data were obtained in 1961-1962 during the period of stable operation of the electric power station. Studies made in 1961 (2292 air samples) showed the zone of high content of sulfur dioxide in atmospheric air to lie between 0.5 and 6 km. The peak concentrations in this zone were 5-8 times as high as the established sanitary norm (2.53-4.03 mg/m^3). In 1962 (4502 air samples), the maximum, frequently observed sulfur dioxide concentrations did not exceed 1.56 mg/m^3. The zone where high concentrations were recorded was located within a range of 1-5 km, i.e., almost coincided with the one resulting from the data of 1961. The graph (Fig. 1) shows the distribution of sulfur dioxide concentrations in the zones. It is evident from the figure that the sulfur dioxide content of atmospheric air falls below the maximum permissible single concentration of 0.5 mg/m^3 only at a distance of 15-16 km from the source of discharges. According to the average of maximum values, the gas pollution of the atmosphere remains high only in the 2-3 km zone where the peak concentrations were observed. The percentage of air samples in which the sulfur dioxide concentrations was higher than MPC was highest (up to 50%) also in the 1-5 km zone where the maximum concentrations were observed. The data of studies made in 1963 are very heterogeneous because of a partial conversion of the SREPP to gas, but on the whole, they attest to a considerable decrease of the gas pollution of atmospheric air. Thus, under winter weather conditions, of 854 air samples taken under the plume at various distances from the SREPP but no farther than 8 km, in 703 samples the sulfur dioxide concentration was found to be below the sensitivity limit of the chemical determination method. In addition, the highest single concentration (1.02 mg/m^3) was close to the level of maximum air pollution of the winter studies of 1962. During the summer period of studies made in 1963 (1739 air samples), because of a decrease in the overall discharge of sulfur dioxide, the study of the dynamics of its progagation in the atmosphere was confined to a radius of 10 km. The total quantity of air samples with concentrations above the sensitivity limit of the determination method was 70%.

The total number of suction air samples taken in 1960-1963 around the SREPP and analyzed for dust (fly ash) was 1679. Data on the pollution of atmospheric air with dust are listed in Table 1. Under conditions of stable operation of the SREPP (1961-1962), the zone of high dust content, which was 4-7 times as high as the maximum permissible single concentration, was found to be located between 1 and 6 km from the source of discharges, this being in good agreement with the boundaries of the belt of maximum gas pollution of atmospheric air. The highest dust concentration was determined in 1960 at a distance of 3 km to be 4.62 mg/m^3.

Table 1

Maximum Dust Concentrations in mg/m^3 in Atmospheric Air Around the SREPP in 1960-1963.

Year	Season	No. of Samples	Distance in Kilometers											
			0,5	1,0	2,0	3,0	4,0	5,0	6,0	8,0	10,0	12,0	15,0	20,0
1960	Winter	178	2,33	1,76	0,97	4,62	3,40	1,48						
1961	Summer Autumn	578	1,62	1,92	1,63	2,30	2,08	2,49	2,96	1,05				
1962	Winter Spring Summer Autumn	696	0,56	1,20	2,46	3,13	2,77	3,38	1,46	1,38	0,65	0,89	0,47	0,33
1963	Winter Spring Summer	227	0,33	0,96	2,06	0,83	0,17	0,23						

Studies made in 1962 established that the zone of high dust content of the atmospheric air around the SREPP, not permissible from the sanitary-hygienic standpoint, is defined by a distance of 15 km.

The high dust content in atmospheric air in the 0.5 km zone closest to the source of discharges (maximum concentration 2.33 mg/m^3) is explained by the presence of unorganized steady sources of dust (coal yard, unloading of coal) on the industrial site of the SREPP, and also by the settling of coarse ash particles from the atmosphere after their discharge from the stacks of the electric power plant. This conclusion is confirmed by studies of the particle size composition of air samples collected by the suction method for the purpose of determining the gravimetric dust content of atmospheric air (Table 2). Studies of the particle size compositions were carried out on 129 air samples by brightened field microscopy in filters of FPP-15 cloth. As follows from Table 2, 50.8% of the dust in the air samples collected in the 0.5 km zone consisted of particles 20-50 microns in size or larger. These data correlate satisfactorily with the results of studies made by the SATOEREPPN team for the purpose of determining the fractional composition of the ash discharged into the atmosphere; according to these results, the fraction of dust particles measuring 50-100 microns or more accounts for 50% in the discharge of inadequately purified waste gases. In the zone of highest dust concentrations in the atmosphere (1-6 km from the source of discharges), the proportion of particles measuring from 0 to 5 microns ranged from 30.8 to 68.9%. Thus, the zone of maximum weight pollution of atmospheric air with dust (fly ash) is at the same time the most dangerous hygienically in particle size composition. Because of a partial conversion of the SREPP to gas in 1963, the air pollution data indicate a marked decrease of dust pollution (see Table 1). Of 227 air samples, 150 were positive. The 5 km distance was found to be the zone in which negligible dust concentrations were still observed (maximum 0.23 mg/m^3). The maximum value of the dust pollution was 2.06 mg/m^3, observed at a distance of 2 km, indicating a heavy pollution of the atmosphere in the 1-3 km zone of maximum concentrations, even when the average total consumption of Moscow coal by the electric power station was reduced by a factor of 3.

Table 2

Particle Size Composition of Dust (Fly Ash) in Atmospheric Air Around the SREPP in %.

Distance, km	0,5	1,0	2,0	3,0	4,0	5,0	6,0	10,0	15,0	20,0
Size, Microns										
0—3,0	6,4	10,0	12,4	22,5	31,5	33,8	35,4	45,4	48,4	45,7
3,0—5,0	4,7	20,8	22,4	29,0	32,1	32,4	33,5	34,9	37,0	37,2
5,0—10,0	15,2	21,3	23,1	23,7	20,2	18,8	18,8	14,8	9,8	13,7
10,0—15,0	13,2	18,4	18,4	12,6	8,7	8,9	7,6	3,7	3,5	2,6
15,0—20,0	9,7	14,3	9,8	7,4	4,0	3,9	2,5	0,8	0,8	0,8
20,0—30,0	14,5	8,3	6,6	3,6	1,8	1,3	1,3	0,4	0,5	—
30,0—50,0	14,8	4,4	4,3	0,9	1,0	0,7	0,6	—	—	—
50,0 and larger	21,5	2,2	3,1	0,3	0,7	0,2	0,3	—	—	—
Total	100	100	100	100	100	100	100	100	100	100

To supplement the studies of pollution of air with sulfur dioxide and dust, an inquiry was conducted among the population living in the area studied. A total of 478 persons were questioned within a 10 km radius of the SREPP. Complaints of the effect of dust and odor, particularly with a wind, were characterized by an increase of positive replies as one moved away from the source of discharge. Thus, whereas at a distance of 2 km only 60% of the total number of inhabitants questioned noted the presence of an odor, in the 3 km zone the percentage of positive answers was 88.2%, and at a distance of 4 km, 95.9%. In all of the succeeding zones, it remained relatively high, 81-96%. Among subjective complaints, the most significant pertained to irritation of the eyes, which, starting at a distance of 3 km, amounted to 94.5-97.0% of all the persons questioned. An adverse effect of the discharges on green plantings and garden plants was noted by the population at all distances, with the largest number of complaints in the 3-8 km zone. The negative effect on garden plants is manifested, for example, during the period of florescence and formation of cucumbers (wilting and shriveling), and in the development of the cabbage head. Prematurely yellow tree leaves and an early defoliation are characteristic of the area of the SREPP.

CONCLUSIONS

1. Comprehensive studies provide a detailed and all-inclusive description of the conditions of diffusion of industrial discharges (dust and gases) in the surrounding atmosphere.

2. The region of high content of dust and sulfur dioxide (above MPC) in the ground layer of atmospheric air around a high capacity SREPP for a stack height of 120 m is defined by a radius of 15 km.

3. The zone of maximum concentrations is located within a range of 1 to 6 km, the highest dust concentration being 4.62 mg/m^3 and sulfur dioxide concentration, 4.03 mg/m^3.

4. The zone of maximum dust concentrations is hygienically the most unfavorable in particle size composition, since the number of particles from 0 to 5 microns in size ranges from 30.8 (1 km) to 68.9% (6 km) in the samples.

5. Data of an inquiry conducted among the population within a 10 km radius of the SREPP confirm the adverse influence of discharges of the thermal electric power plant on the sanitary living conditions of the population.

DISCHARGE OF FLUE GASES AND ASH BY ELECTRIC POWER PLANTS AND CALCULATION OF THEIR CONCENTRATIONS IN THE ATMOSPHERE

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p. 3-55

Introduction

The operation of a modern high-output electric power plant involves the discharge of mostly noxious substances into the atmosphere. During the combustion of solid fuels (coals, shales, peat), in addition to CO_2 and water vapor, the following substances are discharged into the atmosphere: ash, sulfur oxides, nitrogen oxides, and small amounts of products of incomplete chemical and mechanical combustion of the fuel (soot, coke particles, carbon monoxide, hydrogen sulfide, and other gases).

In the combustion of energy-producing fuels (fuel oil), the noxious portion of the discharges consists mainly of sulfur oxide, nitrogen oxides, and a small amount of ash, soot, and coke particles. Despite the low content of ballast in fuel oil, its combustion is associated with a considerable pollution of the ambient air. Thus, the combustion of about 80 thousand tons of sulfur-bearing fuel oil per day in one of the industrial areas was associated with a daily discharge of 2270 tons of SO_2, 1220 tons of NO_2 and 210 tons of fly ash into the atmosphere.

In the combustion of natural gas, the main pollutants of the atmosphere are nitrogen oxides. Small amounts of aldehydes and soot particles also reach the atmosphere.

The formation of noxious substances and their quantitative discharge during the combustion of various fuels also depends on a number of factors. The amount of sulfur dioxide discharged into the atmosphere depends only on the fuel composition, whereas the amount of other pollutants depends also on such factors as the structure of the furnace chamber, the mode of feeding air into the furnace, the furnace temperature, the design and arrangement of the burner units, etc.

The discharged substances have different degrees of noxiousness. Considering the scale of their discharge, sulfur dioxide and fly ash are the most noxious components at the present time. A certain danger also has begun to be posed by steadily increasing discharges of nitrogen oxides. Sulfur dioxide has an adverse effect on human health, inhibits the growth of vegetation and in some cases causes its destruction, poisons the soil, causes the corrosion of metals, and damages the construction of buildings.

The presence of SO_2 in air in concentrations exceeding 2 mg/m^3 causes irritation of the human mucous membranes, and on prolonged exposure, a chronic inflammation of the respiratory tract. Pollution of the atmosphere with fly ash and dust has an adverse effect on the sanitary living conditions of the population. The local climatic conditions deteriorate in the region of the discharges. Water vapor condenses on the dust particles, promoting the formation of fogs. Dust particles markedly decrease the transparency of air and absorb a considerable portion of ultraviolet rays.

The pollution of the atmosphere with noxious substances causes enormous damage to the national economy. According to the journal "Courier UNESCO", the damage caused to crops in the U.S.A. in 1950-1951 was 1.5 billion dollars, the loss in England for the same period was estimated at 100 million pounds sterling, and in France, 240 billion francs (old).

Thus, the problems of protection of the air reservoir have now assumed a special urgency in many industrial countries, including ours. A system of standardization of atmospheric pollution regulating the maximum permissible concentrations of noxious substances in air is now in force in the USSR (Table 1, Appendix I). A special conservation law passed in the RSFSR in 1960 and corresponding legislation of the Union Republics have set forth provisions for the protection of atmospheric air. The State Sanitation Inspection has been charged with supervising the enforcement of these regulations.

The protection of atmospheric air from the noxious discharges of electric power plants is now being organized by implementing a set of preventive measures: removal of solid ash and soot particles from the flue gases, dispersal of dust and noxious gases through high stacks, developing conditions and modes of fuel combustion such that the minimum possible amount of noxious substances reaches the atmosphere under a given set of conditions. Although these measures do not always reach their objectives, particularly with regard to the discharge of noxious gases, they nevertheless permit a considerable reduction in the concentration of the discharges near the ground and an improvement in the sanitary state of the atmosphere in the zone of the electric power plant.

This paper, which can be used as a manual, discusses some aspects of the evaluation of the efficiency with which carryover ash is removed from flue gases in the types of ash collecting devices adopted by electric power plants and describes a method for calculating the concentration of discharges in the ground layer of air and a method for calculating the parameters of smokestacks. The paper is designed as an aid in carrying out a typical calculation and for homework in a course on "energy-producing fuel and gas purification" and may be used by students of a heat and power engineering department working on class and diploma projects concerning a thermal electric power plant and also by students in other departments working on a design of the thermal part of an electric power plant.

1. Dispersal of Discharges from Smokestacks and Calculation of Concentrations of Fly Ash and Gases in the Atmosphere.

The dispersal of discharges from smokestacks is a very complex process for which no exact mathematical description has been proposed thus far. The gaseous components of the smoke jet and fine dust (less than 60 μ in size) spread in the atmosphere in accordance with the laws of turbulent diffusion. The process of spreading of flue gas jets is affected by a large number of different factors, many of which are subject to change in time and space. The greatest influence on the dispersal of discharges is that of atmospheric turbulence, which in turn depends on the roughness of the earth's surface and on the weather conditions - the wind velocity and the character of the temperature change with height (the so-called temperature stratification of the atmosphere).

The roughness of the earth's surface promotes the generation of eddies during the movement of air masses, and the temperature stratification affects the vertical velocity of these eddies.

Three states of the ground layer of the atmosphere are distinguished from the standpoint of its temperature stratification:

1. The state of convection, arising from a decrease of the temperature with the height. In this case, the turbulent mixing of the air masses is the greatest, and the state of the atmosphere is unstable.

2. The state of inversion, characterized by an increase of temperature with the height. In this state, the atmosphere is characterized by a minimum turbulent mixing and is the most stable.

3. The state of isothermalcy, in which the temperature changes little with the height (up to ±1° per 100 m of height).

In this case, the atmosphere is in a state of indifferent equilibrium.

The convection state of the atmosphere usually takes place in the daytime hours, whereas the inversion state occurs at night and during periods of continuous low cloudiness (frequent near maritime zones).

The stratification of the atmosphere is quantitatively characterized by the parameter ε, which is a function of the temperature difference and wind velocity. In the ground layer of the atmosphere

$$\varepsilon = f\left(\frac{\Delta T_{0.5:2}}{u_1^2}\right)$$

where ΔT is the temperature difference at heights of 0.5 and 2 m;
u_1 is the wind velocity at this level.

When $\varepsilon > 0$ (+0.1 to +0.2), the stratification of the atmosphere is stable; when $\varepsilon < 0$ (-0.1 to -0.3), it is unstable; when $-0.05 \leqslant \varepsilon \leqslant +0.05$, the atmosphere is characterized by an indifferent equilibrium. The roughness of the surface is characterized by coefficient S, which is determined from measurements of the wind velocity at several heights during an indifferent equilibrium. It has been found that S is proportional to the average size of the irregularities; at the same time, the proportionality coefficient ranges from 0.2 to 0.01, increasing from well-streamlined to poorly streamlined surfaces. The values of coefficient S are listed in Table 2 of Appendix I).

In addition to the indicated factors, the process of dispersal of discharges and the magnitude of their concentration at a given point are affected by the scale of the discharge and its character, and the temperature and velocity of the flue gases leaving the stack. It may be approximately assumed that a jet of flue gases escaping from the tube is inscribed into a cone whose vertex is located on an extension of the stack axis, the axis of the cone being parallel to the earth's surface (Fig. 1). Accordingly, the rectangular coordinate system taken for the calculation is located so that axis OX coincides with the projection of the smokestack axis on the ground (corresponds to the direction of the wind), axis OZ coincides with the stack axis, and axis OY is in the plane of the ground, perpendicular to axis OX.

The concentration of noxious gaseous impurities and other fire particles in a smoke jet will gradually decrease from the axis of the cone to its generatrices in the radial direction, where a continuous mixing of the flue gases with the ambient air takes place. At point A at a certain distance from the stack, the smoke jet will touch the earth's surface, having defined the starting boundary of the pollution zone. As the jet spreads farther from point A, the concentration of impurities in the ground layer of air increases, reaches a maximum, then slowly decreases as a result of mixing of the gases with the ambient air. In the direction perpendicular to the spreading of the smoke jet, the concentration of impurities decreases on both sides of axis OX.

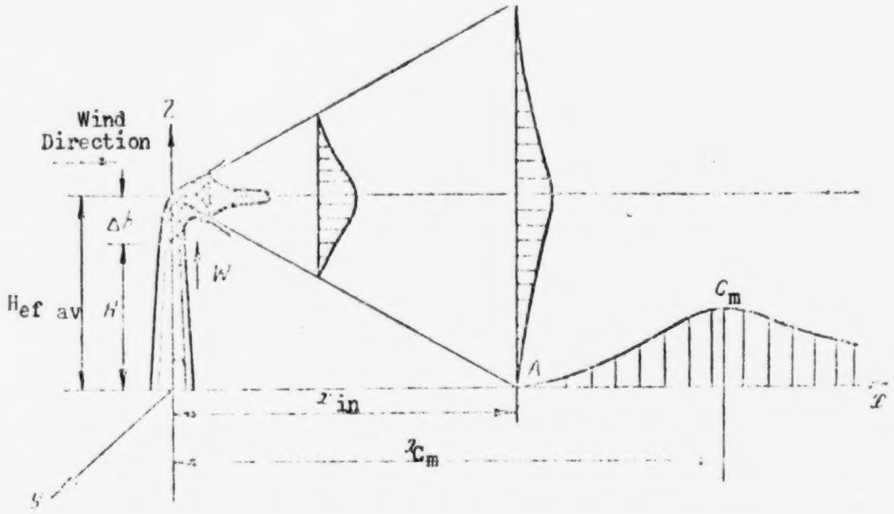

Fig. 1. Spreading of a jet of gases leaving the smokestacks.

The extent of gaseous pollution in the ground layer of air may reach ten or more kilometers depending on the volume of the discharges. Since the washout of the jet proceeds in three measurements, the region of air polluted near the ground usually has parabolic outlines with the vertex of the parabola located on the axis of the projection of the smoke jet on the ground (axis OX) at the point where the pollutants appear.

In accordance with the requirements of the State Sanitation Inspection, the calculation of the pollutant concentrations should be carried out along axis OX at two levels: at a height of 2 m (breathing level) and at the level of the upper floors of the highest residential buildings. The main quantity to be calculated is the maximum single concentration of the impurity, corresponding to its maximum hourly discharge into the atmosphere. The maximum mean daily concentration is calculated by taking into account the winds for the given topography; here the percent frequency of winds blowing from the point of discharge along the direction toward the calculated point should correspond to the monthly wind rose of an unfavorable month.

The calculations are made for a series of wind velocities beginning with the upper limit of a calm (0.5 m/sec).

The sanitary operating conditions of an electric power plant are considered normal if the calculated concentration of the pollutant does not exceed the permissible norm at any point of the populated area. If an excess over the maximum permissible pollutant concentrations has been established by calculation at a given point of the area, the frequency with which this excess will take place is determined.

Analysis of the process of dispersal of the discharges shows that the maximum single concentration of a pollutant in the atmosphere, obtained by calculation for the given point, will be a relatively rare phenomenon. Indeed, for a uniform wind rose, which is the least favorable from the standpoint of the discharge at the location of the power plant and settlement, the probability of duration of the action of the maximum impurity concentration at a given point of the area is defined as the ratio of angle β within which the impurity concentration approaches the maximum to the total surrounding region. Since in the smoke jet the concentration of its components has a maximum value in the central portion only, the magnitude of angle β does not exceed 10°, although the angle of dispersal of the smoke jet is much larger. It follows that the probability of duration of the action of the maximum pollutant concentration under a given set of conditions does not exceed the ratio $10:360 = 1:36$, which corresponds to a total of approximately 10 days per year.

Since the wind rose usually is not regular, in a correct selection of the location of an electric power plant, the duration of the action of the maximum concentration on a given point of the area will be less than ten days per year. Thus, in evaluating the noxiousness of certain impurities discharged into the atmosphere, it is necessary to consider not only the magnitude of their maximum concentration but also the probable duration of their action.

The calculation of concentrations of dust and gaseous discharges into the atmosphere in the presence at height h (height of smokestack) of a stationary discharge point source of output Q, for dust discharges settling in a gravity field at a constant rate w and for a gas whose settling effect can be neglected (w=0), consists in solving a turbulent diffusion equation of the form

$$u\frac{\partial q}{\partial x} - w\frac{\partial q}{\partial z} = \frac{\partial}{\partial y}\left(K_y\frac{\partial q}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial q}{\partial z}\right) + Q\delta(x)\,\delta(y)\,\delta(z-h),$$

where x, y, z are the coordinates of the points where the impurity concentration is determined;

K_y and K_z are the coefficients of horizontal and vertical diffusion;

u is the average wind velocity;

δ is a delta function.

The last term of the equation takes into account the presence of a point source on axis OZ at point z=h. The effect of diffusion in the direction of the wind is neglected here.

Various authors have proposed a number of computing formulas based on the turbulent diffusion equation. All the formulas derived are single-valued and differ mainly in the numerical value of certain empirical coefficients estimating the influence of various additional factors on the diffusion of the discharges. The values of the discharged concentrations computed from the various formulas differ substantially from each other and from the experimental data.

This discrepancy is chiefly due to different approaches to the treatment of the experimental material on the basis of which the authors of the formulas selected the empirical coefficients.

In the USSR, one of the most widely employed formulas is that of P. I. Andreyev,

$$C = \frac{1000M}{\pi\cdot C_y\cdot C_z\cdot v_0\cdot x^{2-n}}\cdot e^{-\frac{y^2}{C_y^2\cdot x^{2-n}}}\left[e^{-\frac{(z-H_{\text{eff}})^2}{C_z^2\cdot x^{2-n}}} + e^{-\frac{(z+H_{\text{eff}})^2}{C_z^2\cdot x^{2-n}}}\right]. \tag{1}$$

where C is the concentration of gases or dust in air, mg/m^3;

M is the discharge of gas or dust, g/sec;

C_y, C_z are the dispersal coefficients in the horizontal and vertical directions respectively (for average conditions, $C_y = C_z = 0.05$);

x, y, z are the coordinates of the point for which the calculation is made, m;

n is a coefficient allowing for the temperature gradient and roughness of the area (the values of n are in the range of 0-0.5);

H_{eff} is the effective height of the discharge, given by the expression

$$H_{eff} = H + \Delta h,$$

where H is the stack height, m;

Δh is the height of ascent of the gases above the stack orifice, m;

The magnitude of Δh is given in this case by the formula

$$\Delta h = \frac{1{,}9D\cdot w}{v_0}\ \text{м}, \tag{2}$$

where D is the diameter of the stack orifice, m;

w is the velocity of the gases at the exit from the stack, m/sec;

v_o is the wind velocity at the stack orifice, m/sec.

The wind velocity usually increases with the height and for any point of the height may be calculated from the relation

$$v_o = \phi v_0,$$

where v_c is the wind velocity at a height of 10 m (usually given in weather reports for the given area. On the average, it may be assumed to range from 4 to 6 m/sec);

ϕ is a coefficient taking into consideration the change of the wind velocity with the height.

Values of coefficient ϕ as a function of height H are given below:

H, m	φ	H, m	φ	H, m	φ
10	1,00	80	1,46	160	1,60
20	1,15	100	1,50	180	1,63
40	1,30	120	1,54	200	1,65
60	1,40	140	1,57	220	1,67

In the calculation of the maximum concentration of discharges near the ground (z = 2 m) and direction of motion of the smoke jet along axis OX (for y = 0), assuming $C_y = C_z = 0.05$, and the distance to the point with maximum concentration x_m being equal to the 20-fold effective height of the discharge, Andreyev's formula assumes the following simple form:

$$C_m = \frac{235M}{Kv_0H^2}\ \mathrm{mg/m^3}, \qquad (3)$$

where K is a coefficient which according to Andreyev is equal to 2.5.

The values of C_m obtained from Andreyev's formula correspond to twenty-minute measurements of the corresponding indices, whereas the values of the maximum permissible impurity concentrations in air were established on the basis of data of twenty-minute (maximum single concentrations) and mean daily (maximum mean daily concentrations) measurements corresponding to the meteorological indices.

In this connection, for the purpose of comparison with the maximum single permissible concentrations of pollutants (equal to 0.5 mg/m^3 for SO_2), according to Andreyev, the values of C_m obtained by calculation should be reduced by a factor of 2.5.

On the basis of a comparison of calculated data obtained from Andreyev's formula with averaged data of actual measurements made by the staff of the Erisman Institute of Hygiene in the area of one of the State Regional Electric Power Plants of the Moscow Regional Administration of the Power Economy, the Moscow branch of the All-Union State Planning Institute has recommended that coefficient K in Andreyev's computing formula be taken equal to 16 in the calculation of gas pollution and to 6.25 in the calculation of dust pollution. A number of experts have noted that the values of coefficient K proposed by the Moscow branch of the All-Union State Planning Institute have not been adequately substantiated. The Hygiene Institute considers it possible to use the coefficient K=2.5 in calculations of dust pollution by Andreyev's formula and K=7.5 in calculations of the gas pollution (for SO_2 and NO_2).

N. F. Dergachev has proposed a formula whose simplified variant has the following form:

$$C_x = \frac{9M\cdot e^{-\frac{4,5H^2_{\mathrm{eff}}}{S^2\cdot x^2}}}{\pi v_0\cdot S^2\cdot x^2}\ \mathrm{mg/m^3} \qquad (4)$$

where M is the discharge of gas or dust, mg/sec;

x is the distance from the stack, m;

v_0 is the wind velocity at the stack orifice, m/sec;

S is the turbulence coefficient of the atmosphere (taken as 0.25 for an isothermal state of the atmosphere);

H_{eff} is the effective stack height, m.

H_{eff} is given by the expression

$$H_{eff} = H + \Delta h, \text{ m},$$

where H is the actual stack height, m;

Δh is the height of ascent of the gases above the stack owing to the kinetic energy of the gases and the density differences between the stack gas and air.

Δh may be calculated from the formula

$$\Delta h = \frac{3{,}41Dw}{v_0\varphi} \text{ m}, \tag{5}$$

or from the formula

$$\Delta h = 4{,}2D\left(\frac{w}{v_0} - 0{,}7\right)^{0{,}6} \text{ m}, \tag{6}$$

where D is the diameter of the stack orifice, m;

w is the exit velocity of the gases from the stack, m/sec;

v_0 is the wind velocity at the stack orifice, m/sec.

In the simplified formula, as in Dergachev's main formula, some factors affecting the dispersal of impurities in the atmosphere also remain neglected. The accuracy of the calculation by Dergachev's formula is of the same order as that obtained with Andreyev's formula.

Recently, D. L. Laykhtman, working at the Leningrad Hydrometeorological Institute (LGMI), proposed a formula which includes to some extent all of the main factors affecting the dispersal of gaseous impurities according to the laws of diffusion. The formula has the following form:

$$C_x = \frac{Q}{\sqrt{2\pi\overline{y^2}}} \cdot \frac{Z_1^{1-\varepsilon}}{I_p\left(1 - \frac{\varepsilon}{m+\varepsilon+1}\right)(m+\varepsilon+1)K_1 \cdot x} \times$$

$$\times \left(\frac{u_1 Z_1^{(m+\varepsilon-1)}}{(m+\varepsilon+1)^2 \cdot K_1 x}\right)^{-\frac{\varepsilon}{m+\varepsilon+1}} \cdot e^{-\frac{u_1 H^{m+\varepsilon+1}}{(m+\varepsilon+1)K_1 Z_1^{m+\varepsilon-1} \cdot x}} \text{ mg/m}^3, \tag{7}$$

where Q is the discharge of gas or dust, g/sec;

$\overline{v^2}$ is the variance of the particle sizes (approximately $\sqrt{\overline{y^2}} = 0.2\, x^{0.9}$);

u_1 is the wind velocity at the height of the discharge, m/sec;

ε is a parameter characterizing the stratification of the atmosphere;

m is a parameter dependent on the roughness of the surface and stratification of the atmosphere;

K_1 is the turbulence coefficient at the height of the discharge;

Z is the height at which the discharge concentration is determined, m;

x is the distance from the point of discharge along the direction of the wind, where the discharge concentration is determined, m;

H is the height of the discharge source (stack height), m;

I_p is a Bessel function of the first kind for an imaginary argument.

In order to use Laykhtman's formula for practical purposes, it is necessary to have tabular data of the values of ε for different times of the year.

Among the formulas proposed abroad, we should mention Sutton's familiar formula

$$C = \frac{2Q}{\pi \cdot C_y \cdot C_z \cdot v_0 x^{2-m}} \cdot e^{-\frac{H^2}{C_z^2 x^{2-m}}} \quad \text{mg/m}^3, \tag{8}$$

where Q is the discharge of gas or dust, mg/sec;

C_y, C_z are empirical coefficients defining the state of the atmosphere;

H_{eff} is the effective stack height, m;

m is an empirical coefficient;

v_0 is the wind velocity at the stack orifice, m/sec.

Sutton's formula also gives very approximate calculated results. It does not take into account the characteristics of turbulence in the ground layer of the atmosphere, so that it fundamentally cannot describe the entire concentration field at the earth's surface. Only when the coefficients C_y, C_z and m are chosen correctly, does the formula satisfactorily agree with the data of air sample analysis in a given region and under certain atmospheric conditions (close to those of stability).

A more precise formula than Sutton's is that proposed by Bosanquet and Pierson.

For calculating the concentration of dust and gaseous discharges near the earth's surface, the formula has the form

$$C_{(z=0)} = \frac{Q}{\sqrt{2\pi} \cdot b_y \cdot b_z \cdot u \cdot x^2} \cdot e^{-\left(\frac{H}{b_z x} + \frac{y^2}{2b_y^2 x^2}\right)} \quad \text{mg/m}^3, \tag{9}$$

where Q is the discharge of the pollutant being determined, mg/sec;

H is the stack height, m;

u is the average wind velocity, m/sec;

x, y, z are the coordinates of the point for which the calculation is made, m;

b_y, b_z are empirical constants characterizing the state of the atmosphere and the process of diffusion therein (on the average, their values are 0.08 and 0.05 respectively).

The advantages of the Bosanquet-Pierson formula, particularly over Sutton's formula, are that the coefficient of vertical diffusion is assumed to increase linearly with the height

$$K_z = b_z \cdot u \cdot z,$$

which corresponds to the reality in the case of a zero temperature gradient.

The coefficient of horizontal diffusion was also assumed by the authors to increase linearly. The increase takes place with increasing distance from the source of discharge in the direction of the wind

$$K_y = b_y^2 \cdot u \cdot x.$$

By performing a series of transformations, A. I. Denisov obtained the so-called generalized Bosanquet-Pierson formula from which the concentration of impurities in the atmosphere can be calculated at any height. For a gaseous impurity and fine dust (d $\lessdot$ 60 μ), the formula in Denisov's interpretation has the following form:

$$C = \frac{Q}{\sqrt{2\pi} \cdot b_y \cdot b_z \cdot u \cdot x^2} \cdot e^{-\left(\frac{y^2}{2b_y^2 \cdot x^2} + \frac{z+H}{b_z \cdot x}\right)} + \frac{2\sqrt{z \cdot H}}{b_z \cdot x} \text{ mg/m}^3 \qquad (10)$$

Assuming z=0, one can obtain an expression for determining the impurity concentration at the earth's surface that agrees exactly with the Bosanquet-Pierson formula given above.

As already noted, all the known formulas yield results that differ substantially from each other and from actual measurements. Fig. 2 shows data for calculations of SO_2 concentrations with different formulas and data on the analysis of air samples at various distances from the discharge. As is evident from the results, the discrepancies between the various calculated and experimental data reach very substantial values.

In 1961-1962, a number of scientific research institutes of the U.S.S.R. carried out special studies on the dispersal of dust and gaseous discharges from high stacks in the atmosphere. On the basis of the data obtained, a new method was developed for calculating the concentration of discharges at the earth's surface; it was recommended and confirmed as a provisional method for electric power plants by a resolution of the State Committee on Coordination of Scientific Research of the U.S.S.R.

According to the new procedure, the maximum concnetrations of pollutants (SO_2, NO_2, fly ash) are determined at the earth's surface under the most unfavorable weather conditions.

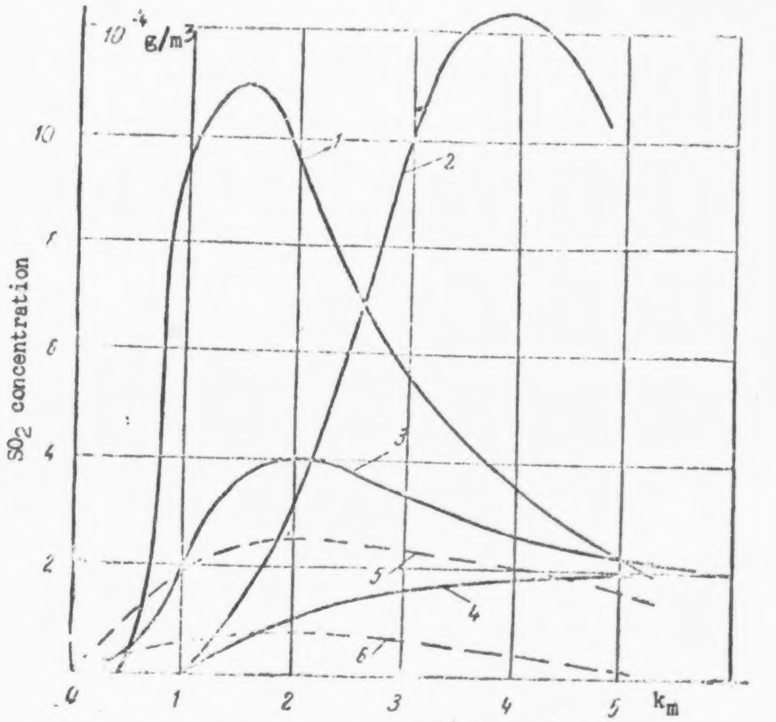

Fig. 2, SO_2 concentration at the earth's surface (for an effective stack height of 200 m and a wind velocity of 10 m/sec): 1 - calculated from Dergachev's formula; 2 - from Sutton's formula; 3 - from the LGMI formula for $\epsilon = -0.1$; 4 - from the LGMI formula for $\epsilon = 0.0$; 5 - from data of air analysis (maximum values); 6 - same (average value).

It is also assumed that the low ground concentrations obtained should not exceed the sanitary norms, otherwise for a given fuel either the stack height is increased, or the bulk discharge (output of the electric power plant) is decreased. The calculation of C_m is carried out by using the formula

$$C_m = \frac{A \cdot F \cdot M \cdot m}{H^2} \sqrt[3]{\frac{n}{V \cdot \Delta T}} \ \text{mg/m}^3 \qquad (11)$$

where A is a coefficient dependent on the temperature stratification of the atmosphere, determining the conditions of vertical and horizontal dispersal, $\text{sec}^{2/3}\ \text{deg}^{1/3}$ (the following values are taken: A = 120 for the central part of the European territory of the U.S.S.R.; A = 160 for the north and northwest of the European territory of the Union, Ural, and the Ukraine; A = 200 for the central part of Siberia, Kazakhstan, and Central Asia);

F is a dimensionless coefficient taking into account the influence of the settling rate of the impurities (in the calculation of SO_2 concentration, F=1; in the calculation of ash concentration, F=2 for $\eta_{ao} \geqslant 90\%$ and F=2.5 for $\eta_{ao} < 90\%$);

M is the total discharge of noxious impurities from stacks of the same height, g/sec;

m is a dimensionless coefficient taking into account the influence of the exit velocity of the gases from the stack w (m = 1 for w = 10-15 m/sec; m = 0.9 for w = 20-25 m/sec; m = 0.8 for w = 30-35 m/sec);

H is the geometric stack height, m;

n is the number of stacks of the same height;

V is the total volume of gases discharged from the stacks, m^3/sec;

ΔT is the difference between the temperature of gases leaving the stack T_g and the temperature of the ambient air T_a, °C.

The values of M_{SO_2}, M_{ash} and V are calculated in accordance with the norms of thermal design of boiler units now in force. Volume V is determined from the fuel consumption corresponding to the rated output of the power plant; it is related to the diameter of the stack orifice D (in m) and also to the average exit velocity of the gases from the orifice w (in m/sec) as follows:

$$V = \frac{1}{4} N \pi D^2 w \ \mathrm{m^3/sec} \qquad (12)$$

In calculating ΔT, T_a is approximately determined from the ground temperature of air by using a climatological reference book for summertime in daytime hours.

Formula (11) is convenient for calculating impurity concentrations for $H > 50$ m, $\frac{V}{n} > 20\ \mathrm{m^3/sec}$, and $\Delta T > 30°C$.

The maximum impurity concentration is reached at a distance X_m equal to a twentyfold stack height

$$X_m = 20H. \qquad (13)$$

The impurity concentration at any distances X different from X_m is determined at the so-called unsafe wind velocity u_m at the height of the wind vane (~10 m). At this velocity, an intense vertical exchange of the air masses arises which leads to a general increase of the concentrations at the earth's surface (the concentration near the earth reaches its maximum value).

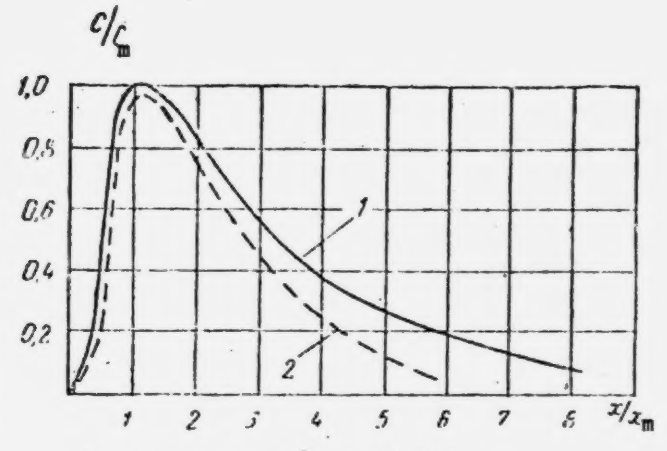

Fig. 3. Graph of $X/X_m = f(C/C_m)$:
1 - discharge of gaseous impurities; 2 - discharge of dust particles.

For high-output thermal power plants, u_m is found from the formula

$$u_m = 0,65 \sqrt[3]{\frac{V\Delta T}{nH}} \text{ m/sec} \qquad (14)$$

The notation here is the same as in formula (11).

To calculate the concentration of the impurity (SO_2 and ash) at distance X, use is made of the graph of $X/X_m = f(C/C_m)$ illustrated in Fig. 3.

Having determined C_m from formula (11) and X_m from formula (13) and taken a value of X, we find C by means of the graph. In the calculation of the impurity discharge, the height of the stacks, their number and diameter and also the exit velocity of the stack gases and temperature drop ΔT should be chosen so that C_m does not exceed the maximum permissible concentration (MPC) of the noxious impurity (in the case of SO_2, MPC = $= 0.5$ mg/m^3).

In this case, the minimum permissible stack height is determined from the expression

$$H = \sqrt{\frac{A \cdot M \cdot F \cdot m}{\text{ПДК}} \sqrt[3]{\frac{n}{V\Delta T}}} \text{ m.} \qquad (15)$$

If the electric power plant discharges pollutants whose maximum permissible concentration does not agree, for example, if there is a simultaneous discharge of SO_2, NO_2 and ash, the stack height should be determined from the highest value of H obtained from formula (15) for each type of discharges taken individually. In particular, if $M_{SO_2} > FM_{ash}$, then

H is established from the discharge of sulfur dioxide, whereas if $M_{SO_2} < F\ M_{ash}$, from the discharge of ash.

The maximum permissible discharges (MPD) of pollutants from electric power plants is determined from the formula (for a given fuel consumption)

$$\text{MPD} = \frac{\text{MPD} \cdot H^2}{A \cdot F \cdot m} \sqrt[3]{\frac{V \Delta T}{n}} \text{ g/sec.} \tag{16}$$

The maximum permissible fuel consumption (MPF) can be determined from the formula

$$\text{MPF} = H^3 \sqrt{\left(\frac{\text{MPC}}{d_1 \cdot A \cdot F \cdot m}\right)^3 \frac{d \cdot \Delta T}{n}} \text{ g/sec,} \tag{17}$$

where $d = \frac{V}{B}$, is the amount of flue gases discharged into the atmosphere per unit weight of fuel;

$d_1 = \frac{M}{B}$, is the amount of pollutant discharged into the atmosphere per unit weight of fuel.

In planning a new electric power plant in an area where atmospheric air is already polluted with the same impurities from other industrial plants, it is necessary to consider this initial or background concentration C_b. In such cases the sum $C_b + C_m$ should not exceed the maximum permissible concentration MPC.

The stack height H should also be correspondingly increased. In the presence of the background concentration, the stack height will be

$$H = H_0 \sqrt{\frac{\text{MPC}}{\text{MPC} - C_b}}, \tag{18}$$

where H_0 is the stack height determined for C_m from formula (11).

The calculation of the maximum concentration of pollutants for an electric power plant with stacks of different heights and different discharge parameters is carried out by summing up the results for each of the stack, using the curves obtained for the variation of the concentration with distance X.

On the total curve thus obtained, the largest concentration of discharges constitutes C_m for the totality of the power plant stacks.

Comparison of the data of the calculation with experimental material has shown that the largest concentrations of sulfur dioxide and ash C_m and also the corresponding distances X_m, calculated from the provisional method and obtained by processing the observations, differ by not more than 20-30%.

The most accurate representation of the scale of air pollution in the region of an operating power plant can be obtained only from direct measurements of impurity concentrations in air at various points of sampling and under various conditions (state of the atmosphere, scale of the discharge, points of discharge, etc.). Half-hourly measurements of the discharge concentrations are usually made. By comparing the expected concentrations obtained by calculation from formulas with the measurements made during the operation of power plants (taking the background into account), one can refine the computing formulas and on the basis of the latter and experimental measurements, predict with adequate precision the magnitude of expected concentrations of pollutants if the scale of the discharge is increased, for example, upon conversion to a fuel of lower quality or upon increasing the output of the power plant. On this basis, the height of new smokestacks to be installed can be calculated.

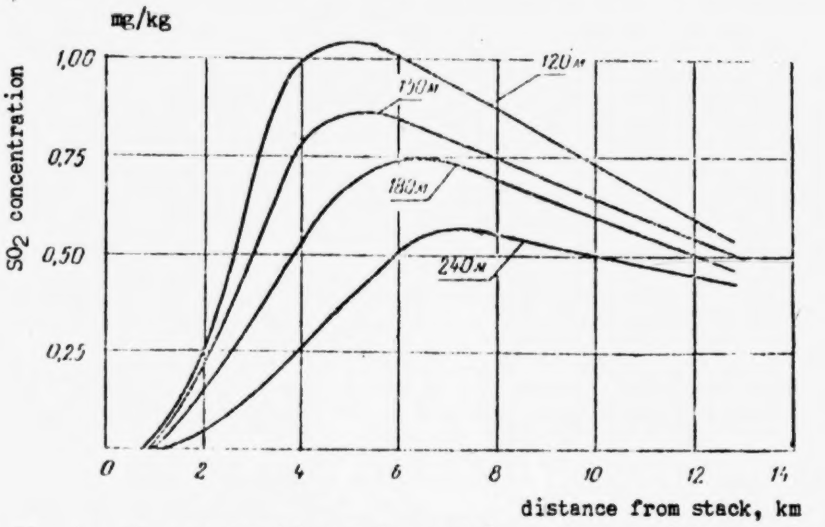

Fig. 4. SO_2 concentration at the earth's surface at different distances from the point of discharge for different heights of the smokestack.

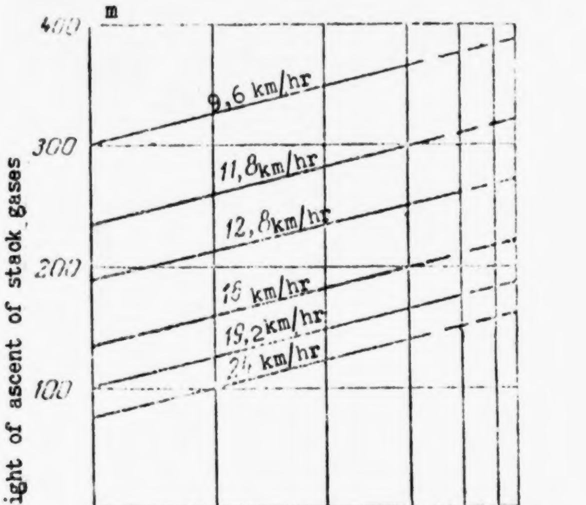

Fig. 5. Maximum height of ascent of the jet of flue gases versus output of power unit and wind velocity.

Fig. 4 shows graphs of such relationships, plotted on the basis of calculations and numerous half-hourly measurements of SO_2 concentration in the area of power plants. Fig. 5 shows the dependence, obtained by observation, of the maximum height of ascent of the jet of flue gases on the output of the power unit and on the wind velocity. As is evident from the graph, the height of ascent increases with the output and decreases with increasing wind velocity. Fig. 4 shows the SO_2 concentrations at various distances from smokestacks of different heights. The relationships were obtained by calculation, using the data of Fig. 5.

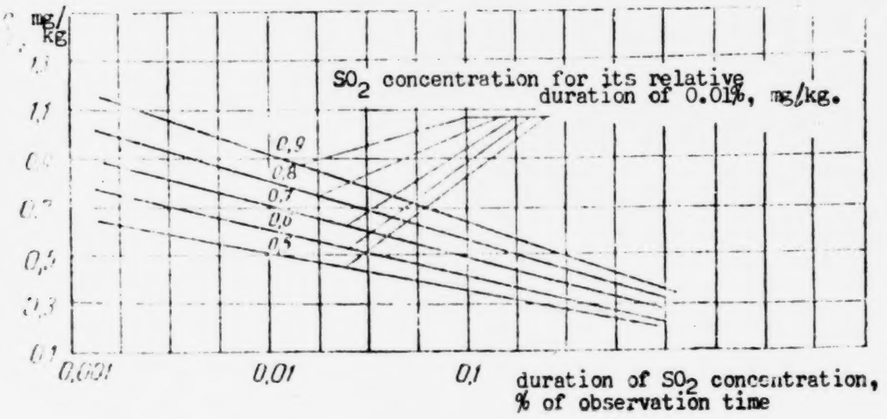

Fig. 6. SO_2 concentration at the earth's surface.

The calculation was performed for a power plant with four smokestacks and with discharge of SO_2 through each stack in the amount of 300 t per day. Since, in order to evaluate air pollution, it is very important to know the duration of the presence of an SO_2 concentration at the breathing level, it is necessary to have a graph of the distribution of the relative duration of the presence of SO_2 concentrations at the given point. Such a relationship, plotted on the basis of observations, is illustrated in Fig. 6. It is evident from this graph that an approximately linear dependence exists between the possible SO_2 concentration and the logarithm of the relative duration of the presence of this concentration.

The data of Figs. 4 and 5 permit one to determine the SO_2 concentration quite accurately at any point in the vicinity of an isolated source of discharge. For instance, in the case of the electric power plant under consideration, an increase of the stack height from 150 to 210 m causes a decrease of SO_2 concentration near the ground (at the breathing level) from 0.87 to 0.65 mg/kg, i.e., by 25.3%. In addition, it follows from the graph (Fig. 6) that the relative duration of the 0.5 mg/kg SO_2 concentration will decrease from 0.22 to 0.06%, i.e., by 72.7%.

Appendix II gives an example of the calculation of the maximum ground concentration of pollutants in accordance with the provisional method of the State Committee on the Coordination of Scientific Research and the current norms of thermal design of boiler units for a thermal-electric power plant.

2. Particle Size Composition of the Carryover and Evaluation of the Efficiency of Operation of Ash Collectors.

The ash, soot and coke particles discharged with flue gases, usually referred to as carryover or fly ash, have dimensions ranging from fractions of a micron (soot) to tens of microns or more (coke particles and ash agglomerates).

The particle size composition of the carryover is usually characterized by the percent distribution of the weight of particles of different coarseness over the particle sizes x expressed in microns (μ). The particle size characteristics of fly ash of various fuels for certain modes of their combustion are listed in Table 1 and Appendix III.

The particle size composition may be expressed either in the form of the function R = f(x), which is an integral durve or curve of total residues, or in the form of distribution curves existing in two forms: a) curve of distribution over fractions (fractional curve) $\Phi = f(x)$; b) curve of distribution over sizes (or partial curve) N = f(x).

An example of the plot of the corresponding functional relationships is given in Fig. 7.

The function $\Phi = f(x)$ can be plotted graphically from the integral curve otherwise referred to as the fineness characteristic, by dividing the size axis into equal intervals and finding the increments of the integral curve within each interval. Thus

$$\Phi = -\frac{\Delta R}{\Delta x}\cdot\Delta x = -\Delta R\ \%.$$

In order to obtain an approximate plot of the function N = f(x), the magnitude of increments ΔR in the size intervals should be referred to the average particle size for this interval; an exact plot of this function, however, is carried out by graphical differentiation of the function R = f(x).

Thus,

$$N \approx -\frac{\Delta R}{\Delta x}\ \% \quad \text{or} \quad N = -\frac{dR}{dx}\ \% \quad \text{or} \quad N = -\frac{dR}{dx}\ \%.$$

An example of a graphical differentiation of the curve R = f(x) is given in Appendix III.

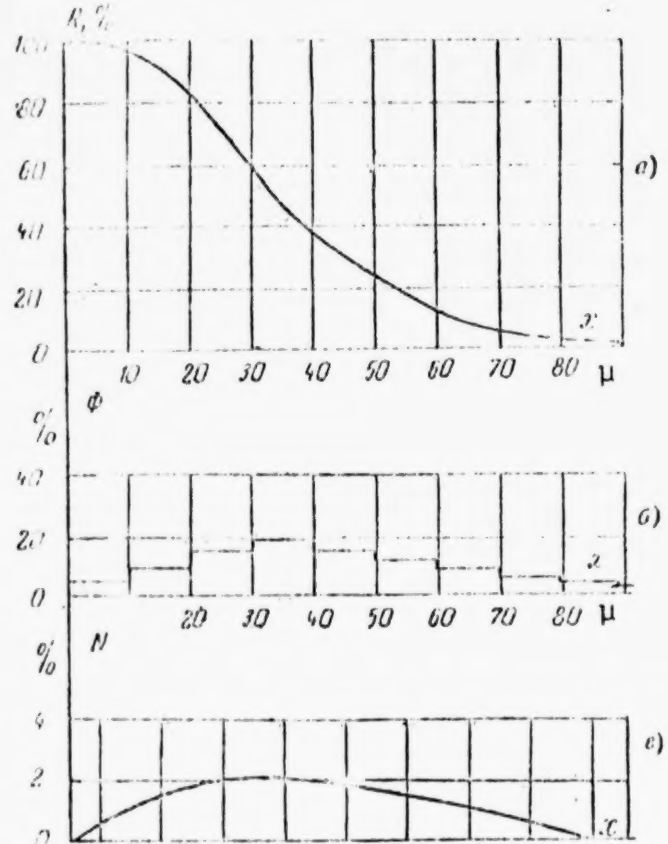

Fig. 7. Particle size characteristics of fly ash
a - curve of total residues; b - fractional curve;
c - partial curve.

In many cases, for example because of the difficulty of separating fine fractions (d<50 µ), the fineness characteristic may lack data for sizes of particles $x \to 0$ and also for particles $x \to \infty$. In subsequent calculations, such an incomplete characteristic must be extrapolated to one side or the other. This is particularly necessary in determining the degree of trapping, since an incomplete accounting of the coarse fractions, whose trapping is usually more effective, leads to an understatement of the degree of purification. In the presence of an incomplete fractional characteristic of the carryover, the curve of total residues is plotted by summing up the fractions, then extrapolated to $R = 0$. After the region of extrapolation has been subdivided into intervals, the complete characteristics $\Phi = f(x)$ and $N = f(x)$ are plotted.

In the case of types of ash-collecting devices designed for installation at electric power plants, the evaluation of their operating efficiency is made on the basis of the degree of purification of the gases η, which is the ratio of the weight of the carryover trapped in the ash collector to the weight of the carryover initially contained in the gases

$$\eta = \frac{G_{en} - G_{ex}}{G_{en}} = \frac{G_{col}}{G_{en}} = \frac{G_{col}}{G_{col} + G_{ex}}, \qquad (19)$$

where G_{en} is the weight of carryover present in the gases before they enter the unit, kg/hr;

G_{ex} is the weight of carryover present in the gases after their exit from the unit, kg/hr;

G_{col} is the weight of carryover collected in the unit, kg/hr.

Since the quantities G_{en} and G_{ex} cannot be determined directly, the degree of purification of the gases is usually determined from the amount of gases being purified and their dust content before and after the ash collector

$$\eta = \frac{aQ_{en} - bQ_{ex}}{aQ_{en}}, \qquad (20)$$

where Q_{en} and Q_{ex} are the amounts of gases entering and leaving the collector, m^3/hr;

a is the average content of carryover in the unpurified gases, g/m^3;

b is the average content of carryover in the purified gases, g/m^3.

When $Q_{en} = Q_{ex}$, we have

$$\eta = \frac{a - b}{a} = 1 - \frac{b}{a}. \qquad (21)$$

To evaluate the sanitary effect obtainable by installing ash collectors, it is more desirable to use the quantity ε denoting the weight of the carryover not trapped by the unit, expressed in fractions of weight of the carryover reaching the ash collector

$$\varepsilon = 1 - \eta = \frac{b}{a}. \qquad (22)$$

A comparative evaluation of the efficiency of the various ash collectors may also be made on the basis of the degree of purification of gases η, but in this case the ash collectors should be tested under the same conditions and for carryover of the same fractional composition. If, however, the fractional composition of the carryover during testing of the units differs considerably, a correct evaluation of their operation on the basis of η is not possible. The composition of the carryover may have a greater influence on the degree of purification of gases in the ash collector than its structual difference from other units. The quantity η of a better unit but tested on carryover containing primarily fine particles may be smaller than that of an inferior unit but tested on coarse carryover.

The comparison of ash collectors under gas purification conditions involving the removal of carryover of different particle size compositions is made by determining the fractional degree of purification of gases $\eta\Phi$. The fractional degree of purification of gases depends on both the design of the ash collector and its dimensions, which affect the velocity of the gases passing through it. The quantity $\eta\Phi$ is equal to

$$\eta\Phi = \frac{G_{\Phi\text{col}}}{G_{\Phi\text{en}}} = \frac{\Phi_{\text{col}} G_{\text{col}}}{\Phi_{\text{en}} \cdot G_{\text{en}}} = \frac{\Phi_{\text{col}}}{\Phi_{\text{en}}} \cdot \eta.$$

Thus, in order to determine η^{Φ}, it is necessary to know the total degree of purification of gases η in the adopted type of ash collector, and the particle size composition of the carryover. Depending on the point of collection of carryover samples, $\eta\Phi$ may be calculated from one of the following expressions:

$$\eta_{\Phi} = \frac{\Delta R'}{\Delta R} \cdot \eta; \tag{23}$$

$$\eta_{\Phi} = \frac{\Delta R - \Delta R'(1-\eta)}{\Delta R}; \tag{24}$$

$$\eta_{\Phi} = \frac{\Delta R' \cdot \eta}{\Delta R' \eta + \Delta R''(1-\eta)}, \tag{25}$$

where ΔR is the content of the given fraction in the carryover before the ash collector, %;

$\Delta R'$ is the content of this fraction in the carryover trapped in the ash collector, %;

$\Delta R''$ is the content of this fraction in the carryover not trapped in the ash collector, %.

The values of ΔR, $\Delta R'$ or $\Delta R''$ are determined from data on the fractional analysis of the carryover, based on curves of total residues (integral curves) or fractional distribution curves.

The graphical interpretation of the calculated values of η_f as a function of the particle size is in the form of a rising stepped line (Fig. 4 of Appendix III).

Knowing the fractional degree of purification, one can determine the composition of the carryover after the ash collector.

Any fraction of particles of carryover discharged into the atmosphere by an ash collector may be determined from the expression

$$\Delta R'' = \frac{\Delta R(1-\eta_{\varphi})}{1-\eta}, \%. \tag{26}$$

Using this formula in calculations of all the successive fractions of the carryover, one can find its fractional composition. By carrying out the same kind of calculations again, but with the carryover composition obtained as a result of the first computation, one can obtain the total degree of purification of gases in the case of two identical ash collectors installed in succession, expressed in percent of the weight of the carryover entering the second unit. The same method can also be used to calculate the composition of the carryover leaving the second unit.

The determination of the fractional composition of the carryover entering the ash collector may be made if the total degree of purification of gases in the unit and the composition of its carryover collected in the unit and remaining in the gas (not trapped) are known. In this case,

$$R_x = R'_x \eta + R''_x (1-\eta), \%, \tag{27}$$

where R'_x and R''_x are the total residues on the sieve with mesh size x for carryover respectively trapped and not trapped in the ash collector, %.

The same expression may be used to determine the fractional composition of carryover not trapped in the ash collector if η, R_x and R'_x are known.

Ash collectors constructed according to appropriate specifications (for example, cyclones), are characterized by more or less definite values of the fractional degree of purification. In this case, it usually becomes necessary to determine the total degree of purification of gases for the given ash collector and the composition of the carryover entering it.

The total degree of purification of gases η is calculated from the formula

$$\eta = \Sigma \eta_{\varphi} \frac{\varphi_{en}}{100}$$

or

$$\eta = \Sigma \eta_{\varphi} \Delta R = \eta_{0-10}(R_0 - R_{10}) + \eta_{10-20}(R_{10} - R_{20}) + \ldots +$$
$$+ \eta_{>60} R_{>60} \ldots \tag{28}$$

The total degree of purification of gases may be also calculated from the results of analysis of three average carryover samples R_x, R'_x, and R''_x, without weighing the trapped carryover, by using the formula

$$\eta = \frac{R_x - R''_x}{R'_x - R''_x}. \tag{29}$$

The calculations are made for the different fractions x, and the arithmetic mean η is taken. As the limits of the particle sizes present in each fraction decrease, the fractional degree of purification is eventually transformed into the so-called partial degree of purification of gases η_p. The values of η_p may be determined from the relation

$$\eta_p = \frac{G_{Ny.i}}{G_{Nex}} = \frac{N_{y.i} \cdot G_{y.i}}{N_{ex} \cdot G_{ex}} = \frac{N_{y.i}}{N_{ex}} \cdot \eta$$

by using one of the following formulas:

$$\eta_p = \eta \frac{dR'}{dR}; \tag{30}$$

$$\eta_p = 1 - (1 - \eta) \frac{dR''}{dR}; \tag{31}$$

$$\eta_p = \frac{\Delta R' \cdot \eta}{\Delta R' \cdot \eta + \Delta R'' (1 - \eta)}. \tag{32}$$

The values of the derivatives may be determined by graphical differentiation of the curves R' = f(R); R" = f(R) and R' = f(R"). Usually, the magnitude of the differential $\frac{dR''}{dR'}$ is determined by graphical differentiation of the graph R' = f(R"), plotted for different values of the particle sizes. The value of $\frac{dR''}{dR'}$ obtained is substituted into the formula for determining η_p, written in the form

$$\eta_p = \frac{\eta}{\eta + (1 - \eta) \frac{dR''}{dR'}}. \tag{33}$$

An example of the plot of the graph R' = f(R") and determination of the differential $\frac{dR''}{dR'}$ is illustrated in Appendix III. The latter also gives values of the partial degree of purification of gases for different ash collectors. Knowing η_p, one can also find the total degree of purification of gases from the formula

$$\eta = \int_0^\infty \eta_p \frac{N_{en}}{100} dx.$$

Transformed, this formula has the form

$$\eta = -\int_{100}^{0} \frac{\eta_p}{100}\, dR = \int_{0}^{100} \frac{\eta_p}{100}\, dR.$$

The graphical determination of the total degree of purification consists in calculating the area bounded by the curve $\eta_p = f(R)$. The function $\eta_p = f(R)$ may be obtained from the graphs $\eta_p = f(x)$ and $R = f(x)$. An example of a graphical determination of the total degree of purification is given in Appendix III.

When an electric power plant is equipped with combined ash collectors consisting of two (or more) units of different types connected in succession, it becomes necessary to determine the fractional composition of the carryover at each stage. The recalculation of each fraction on passing from one stage of collection to the next is carried out by using the formula

$$\Phi'_{ex} = \Phi''_{en} = \Phi'_{en} \frac{100 - \eta'_{\Phi}}{100 - \eta'}, \%$$

or

$$N'_{ex} = N''_{en} = N'_{en} \frac{100 - \eta'_{p}}{100 - \eta'}, \%,$$

where η^1_f and η^1_p are respectively the fractional and partial degree of purification of gases in the first stage, %;

η^1 is the total degree of purification of gases in the first stage, %.

The total degree of purification of gases in the second stage is determined by taking into account the fractional composition of the dust entering the second stage.

The total degree of purification of flue gases in a two-stage ash collector is given by the formula

$$\eta^{tot} = \eta' + \eta'' \left(1 - \frac{\eta'}{100} \right)$$

3. Calculation of Smokestack Parameters and Evaluation of the Maximum Output of Electric Power Plants.

The number and height of smokestacks of an electric power plant are established on the basis of special technical and economic calculations based primarily on the necessity of ensuring normal conditions of atmospheric purity in the region of the power plant, a reliable operation of the boiler units of the plant and a reduction of the capital costs of the construction of the stacks. Considering the high costs of the construction of smokestacks, it is necessary to determine their minimum number for a plant of a given output, but an exact calculation of the number of stacks is still difficult because of the uncertainty of their performance reliability factor. The breakdown of one stack in the case of unit plants results in the cutoff of considerable power, and this in turn necessitates an increase of the reserve in the power system.

Table 1 of Appendix IV gives the possible number of blocks (or boiler units) connected to one smokestack.

On the basis of the experience gained in the operation of large-output thermal-electric power plants, it is currently recommended that one smokestack be installed for blocks with a total output of 1200-1600 MW, appropriate measures being taken to protect the stacks from corrosive attack.

The height of smokestacks may be determined from corresponding formulas for computing the concentrations of pollutants at the earth's surface on the basis of the maximum permissible concentrations (MPC).

In this case, however, it is necessary to bear in mind the relationship between the height of the stacks and the discharge velocity of the flue gases. As the discharge velocity of the gases increases, the maximum permissible concentration of the pollutants near the ground can be obtained with a lower stack height. Thus, as the discharge velocity of the flue gases increases, the costs of the construction of the stack decreases, but the operating expenses go up owing to an increase in the power expended on the draft.

The optimum gas velocity may be determined by a method proposed by L. A. Rikhter* on the basis of a formula relating the gas velocity with the overall costs of smokestacks

$$C = \frac{C_{dr}}{C} V \left[w^2 - 15 \left(\frac{\gamma_a}{\gamma} - 1 \right) H \right] + P'_{std}\, n \cdot L \cdot H^q \, (D + \Delta); \qquad (34)$$

---

* The formula was derived in "Handbook of Methods for Selecting Smokestacks of Electric Power Plants", Moscow Power Institute Press, 1966.

where C are the costs of construction of the smokestacks, (rubles);

C_{dr} are the costs of draft machines, rubles/kW year;

C' is a coefficient dependent on the type of draft machines and type of ash collectors;

V is the volume of flue gases passing through the smokestacks, m^3/sec;

w is the velocity of the gases at the exit from the stacks, m/sec;

γ and γ_a are, respectively, the densities of the flue gases in the stack and in the air surrounding the stack, g/cm^3;

H is the geometric stack height, m;

P'_{std} is a coefficient ($P'_{std} = \frac{\Pi}{100} + P_{std}$, where P_{std} is a standard coefficient of the effectiveness of capital investments, taken as 0.125 in power engineering; Π are the amortization costs, %);

n is the number of stacks at the electric power plant;

D is the diameter of the stack orifice;

L, q and Δ are coefficients obtained in a statistical evaluation of the dependence of the cost of stacks K_{st} in rubles on the height H and orifice diameter D

$$K_{st} = n \cdot L \cdot H^{q} \cdot (D + \Delta). \qquad (35)$$

The values of coefficients L, q and Δ for different stack heights are listed in Table 2 of Appendix IV.

The value of coefficient C' for large electric power plants changes within fairly narrow limits. Values of C' are given below for the following calculation specifications: efficiency of centrifugal flue gas exhaust fan with forward-curved blades $\eta_{st} = 0.59$; efficiency of axial flue gas exhaust fans $\eta_{dr} = 0.8$; motor efficiency $\eta_{mot} = 0.93$; temperature in the smokestack 125°C. for dry ash collectors or without them, and 100°C. for wet ash collectors.

EQUIPMENT	C
Centrifugal flue gas exhaust fans, wet ash collectors	880
Centrifugal flue gas exhaust fans, dry ash collectors and without ash collectors	940
Axial flue gas exhaust fans, dry ash collectors and without ash collectors	1130

The optimum discharge velocity of the gases from the smokestack corresponds to the minimum of the function expressed by formula (34); the velocity of the flue gases enters into the formula in explicit form twice:

in the form of w^2 and in the expression of the stack orifice diameter D

$$D = 1{,}13\sqrt{\frac{v}{n w}} \qquad (36)$$

or

$$D = \frac{C_1}{\sqrt{w}},$$

where

$$C_1 = 1{,}13\sqrt{\frac{v}{n}}.$$

In determining the costs with different values of w, for each gas velocity w one must substitute into formula (34) a stack height H such that C_m remains constant (equal to MPC), since for a constant stack height a change of w will result in a change of C_m.

Once the minimum costs have been found, the optimum flue gas velocity, stack height and stack orifice diameter corresponding to this minimum are determined. When computing formulas including the effective height of the stack are used, its optimum geometric height is determined from the expression

$$H = H_{\text{eff}} - \Delta h.$$

In particular, for Andreyev's formula, Δh depends on the velocity w and stack orifice diameter D

$$\Delta h = \frac{1{,}9 D w}{\varphi v_0} = C_2\sqrt{w},$$

where

$$C_2 = \frac{1{,}9}{\varphi v_0}\cdot C_1.$$

Hence

$$H = H_{\text{eff}} - C_2\sqrt{w}. \qquad (37)$$

When computing formulas of the "Provisional Method" are used, the optimum geometric stack height is determined from the expression

$$H = B_2\sqrt{m} = B_2\sqrt{1{,}125 - \frac{w}{100}}, \qquad (38)$$

where

$$B_2 = \sqrt{\frac{A\cdot M\cdot F}{C_m}\sqrt[3]{\frac{n}{V\Delta T}}}.$$

Here the symbols are the same as in formula (11) of the "Provisional Method". The order of calculation of the smokestack parameters by Rikhter's method consists in the following. Having established the magnitude and type of pollutants (gases or ash) for which the calculation is to be made, one determines the dependence of the geometric stack height H on the velocity of flue gases w for the adopted concentration norm of these discharges near the ground. The costs of the smokestacks are then determined, the number of smokestacks being given first. The cost of the draft machines C_{dr} can be determined from the formula

$$C_{dr} = (P'_{std}K_{mot} + P_{std}K_c)\beta + \frac{\tau\cdot\mu^3}{\eta_{reg}}\cdot a_{pow} \text{ rub/kW year,} \qquad (39)$$

where K_{mot} is the specific cost of the specified power of the electric motors of the draft machines, rub/kW (usually ranging from 10 to 15 rub/kW);

K_c is the cost of the specified power for the drive of these electric motors (cost of the replaceable power of the energy system), rub/kW;

β is the standard reserve of the consumption, pressure and output of the draft machines (β may be taken as 1.3);

τ is the number of hours of operation of draft machines per year;

μ is the load factor for time τ;

η_{reg} is the efficiency of regulation of the draft machines;

α_{pow} is the cost of the electric power supplied to the electric motor, rub/kW-hr.

Taking different values of the velocity of smoke gases w, one plots graphs of the functions C = f(w), H = f(w) and D = f(w). Having found the minimum costs C_{min} from the graph, one determines the optimum values of the stack parameters w_{opt}, H_{opt} and D_{opt}. By comparing the data obtained with the parameters of typical stacks, one selects the most similar of the typical stacks (see Table 1 of Appendix IV).

If no stacks sufficiently similar to the calculated ones have been found, it becomes necessary to design a stack with new dimensions. An example of the calculation of stack parameters for a 2400 kW electric power plant is given in Appendix IV.

The height of smokestacks is related to the values of the maximum output of the electric power plant N_{max} according to the conditions of maximum permissible pollution of the atmosphere with noxious substances. In the case of thermal-electric power plants, their maximum output may be evaluated from the discharge of either ash or noxious gases (SO_2 and NO_2). The use of ash collectors with 90-95% trapping at electric power plants ensures the required purity of atmospheric air for practical purposes from the standpoint of discharge of ash for plants with an output up to 1000 MW operating on fuel of medium ash content. Considering that the best designs of electrostatic precipitators can now ensure a purification of flue gases with up to 99% efficiency, the maximum output of an electric power plant for such ash collectors, even for a high-ash fuel, exceeds the value obtainable under different conditions (demand for water, volume of the equipment, scale of fuel-supplying facilities, etc.).

Because of the lack of any devices for the trapping of noxious gas discharges at electric power plants, the scale of the discharges being taken into account, the evaluation of the maximum output of an electric power plant from the standpoint of sanitary considerations should be made at the present time on the basis of the total discharge of SO_2 (although the discharge of NO_2 does reach substantial values in many cases, it is nevertheless inferior to that of SO_2), or more accurately on the basis of the maximum permissible concentration of SO_2 near the ground. On the basis of computing formula (11) of the "Provisional Method", and taking 0.5 mg/m^3 as the maximum permissible SO_2 concentrations for electric power plants of the European part of the USSR (A = 160), the following formula has been obtained for N_{max} from the sulfur content of burned fuel

$$N_{max} = 0{,}433 \cdot 10^{-3} \cdot H^3 \cdot Q^{w}_{nor} \cdot \eta_c \cdot \eta_{bu} \times \sqrt{\frac{V\left(1 + \frac{T_g}{273}\right)(T_g - T_a)}{n(S^{w} \cdot m)^3}} \text{ MW} \qquad (40)$$

where H is the geometric stack height, m;

Q^{w}_{std} is the heat of combustion of the fuel, MJ/kg;

η_c is the efficiency of α thermal cycle, %;

η_{bu} is the efficiency of the boiler units, %;

V is the total volume of gases discharged into the atmosphere at T_g = 0°C, m^3/sec;

T_g and T_a are respectively the temperature of the gases leaving the stack and the temperature of atmospheric air, °C;

n is the number of stacks;

m is conversion factor;

S^{w} is the sulfur content of the working fuel, %.

As follows from the formula, N_{max} increases markedly with increasing height of the discharge (in the case under consideration, the geometric stack height H) and with decreasing number of stacks.

Appendix I

Table 1

Maximum Permissible Concentrations of Pollutants in the Atmospheric Air of Populated Areas.

Pollutant	Formula	Maximum permissible concentration, mg/m^3	
		Maximum Single	Maximum Mean Daily
Sulfur dioxide	SO_2	0,5	0,15
Nitrogen oxide	N_2O_5	0,3	0,1
Carbon monoxide	CO	—	1
Hydrogen sulfide	H_2S	0,008	0,003
Carbon disulfide	CS_2	0,03	0,01
Metallic mercury	Hg	—	0,0003
Nontoxic dust		0,5	0,15
Carbon black (soot)		0,15	0,05

Table 2

Value of Coefficient S for Various Conditions.

Character of Earth's Surface	Height above Earth, m	S
Smooth	Up to 2	0,027
Slightly dissected, covered with grass	Same	0,0832
Built-up	At roof level	0,20
Built-up	In the range up to three times the height of buildings	0,10—0,12
For any area except mountain regions	Over 100	0,05

Table 3

Wind Velocity at a Given Height Relative to the Wind Velocity at 10 m.

Height, m	Wind Velocity, m/sec	
	Over level area	Over buildings
2,0	0,666	—
20	1,1	1,2
30	1,25	1,35
40	1,32	1,45
50	1,38	1,48
60	1,43	1,51
70	1,48	1,54
80	1,51	1,56
100	1,58	1,58
120	1,64	1,61

Table 4

Particle Settling Rate v_{Π}, m/sec (in still air).

Density of finely divided material, g/cm^3	Particle diameter, μ						
	500	250	100	50	10	5,0	1,0
1,0	2,82	1,33	0,30	0,075	0,003	0,00075	0,00003
1,5	3,45	1,75	0,45	0,110	0,0045	0,0011	0,00005
2,0	4,0	2,17	0,60	0,150	0,006	0,0015	0,00007
5,0	6,3	4,40	1,5	0,375	0,015	0,00375	0,00017

Appendix II

Calculation of Maximum Ground Concentrations of Pollutants Discharged from the Smokestacks of Electric Power Plants.

No.	Item, Notation, Formula and Calculation	Dimensions	Value
1	2	3	4
1	Output of electric power plant N	MW	2400
2	Output and number of units	MW	300×8
3	Type of fuel - anthracite culm (ASh)		
4	Heat of combustion of fuel per working mass Q^{w}_{std}	MJ/kg	25,10
5	Ash content of fuel A^{w}	%	16,7
6	Sulfur content, S^{w}	%	1,7
7	Excess air at exit from smokestack α	—	1,5
8	Heat loss due to mechanical incompleteness of combustion q_4	%	3
9	Fraction of fuel ash carried along by the gases into the gas conduits of the boiler unit a_c	—	0,7
10	Efficiency of ash collecting device (electrostatic precipitators) η_{ac}	%	98
11	Temperature of flue gases at exit from smokestack, T_g	°C	120
12	Temperature of ambient air, T_a	°C	25
13	Number of stacks n (based on one stack for every two 300 MW units)	—	4
14	Diameter of smokestack orifice D	m	7
15	Hourly consumption of fuel (ASh) B for an output of 2400 (8x300) MW (determined from standard specifications of the thermal design of a boiler unit	t/hr	862
16	Volume of flue gases V_g per kg of fuel $V_g = V_{RO_2} + V^{\circ}_{N_2} + V_{H_2O} + (\alpha - 1) V^{\circ} =$ $= 1,35 + 3,25 + 0,40 + (1,5 - 1) \cdot 6,63$	nm^3/kg	10,3

Appendix
(Cont'd)

No.	Item, Notation, Formula and Calculation	Dimensions	Value
1	2	3	4
17	Total volume of gases at exit from smokestack V $V = \frac{V_г \cdot B \cdot 10^3}{3600}\left[\frac{T_g}{273}+1\right] =$ $= \frac{10{,}3 \cdot 862 \cdot 10^3}{3600}\left[\frac{120}{273}+1\right]$	m^3/sec	3540
18	Total discharge of SO_2 from all the stacks M_{SO_2} $M_{SO_2} = \frac{B \cdot 10^6}{3600} \cdot \frac{S^w}{100} \cdot \frac{\mu_{SO_2}}{\mu_S} =$ $= 5{,}56 \cdot B \cdot S^w = 5{,}56 \cdot 862 \cdot 1{,}7,$ where $\mu_{SO_2} = 64$ is the molecular weight of sulfur dioxide; $\mu_S = 32$ is the molecular weight of sulfur	g/sec	8140
19	Total discharge of fly ash M_{ash} $M_{ash} = \frac{B \cdot 10^6}{3600}\left[1-\frac{\eta_{ad}}{100}\right] \cdot \left[1-\frac{q_4}{100}\right] \times$ $\times \frac{A^p}{100} a_c + \frac{q_4}{100} = 0{,}0278 \cdot B\,(100-\eta_{ad}) \times$ $\times (0{,}679\,A^w + q_4) = 0{,}0278 \cdot 862\,(100-98) \times$ $\times (0{,}679 \cdot 16{,}7 + 3)$	g/sec	687
20	Coefficient taking into account the influence of the settling rate of the impurity in the atmosphere F: a) for sulfur dioxide; b) for fly ash	 — —	 1 2
21	Escape velocity of flue gases from stack orifice w $w = \frac{4V}{\pi \cdot D^2 \cdot n} = \frac{4 \cdot 3540}{3{,}14 \cdot 7^2 \cdot 4}$	m/sec	23
22	Coefficient m	—	0,9
23	$\Delta T = T_g - T_a = 120-25$	°C	95
24	Coefficient A	sec$^{2/3}$ × × deg$^{1/3}$	160

Appendix
(Cont'd)

No.	Item, Notation, Formula and Calculation	Dimensions	Value
1	2	3	4
25	Stack height H (found from the discharge of SO_2 since in this case $M_{SO_2} > F\cdot M_{ash}$) $H = \sqrt{\frac{A\cdot M\cdot m\cdot F}{MPC}\sqrt[3]{\frac{n}{V\Delta T}}} =$ $= \sqrt{\frac{160\cdot 8140\cdot 0,9}{0,5}\sqrt[6]{\frac{4}{3540\cdot 95}}}$	m	224
26	The closest large height of typical smokestack H	m	250
27	Maximum concentration of discharge $C_M^{SO_2}$ $C_M^{SO_2} = \frac{A\cdot M_{SO_2}\cdot F\cdot m}{H^2}\sqrt[3]{\frac{n}{V\Delta T}} =$ $= \frac{160\cdot 8140\cdot 1\cdot 0,9}{250^2}\cdot\sqrt[3]{\frac{4}{3540\cdot 95}}$	mg/m^3	0,43
28	Maximum concentration of fly ash discharge C_m^f $C_m^{ash} = \frac{H\cdot M_{ash}\cdot F\cdot m}{H^2}\sqrt[3]{\frac{n}{V\Delta T}} =$ $= \frac{160\cdot 687\cdot 2\cdot 0,9}{250^2}\cdot\sqrt[3]{\frac{4}{3540\cdot 95}}$	mg/m^3	0,07
29	Unsafe wind velocity at wind vane level u_m° $u_m = 0,65\sqrt[3]{\frac{V\Delta T}{nH}} = 0,65\sqrt[3]{\frac{3540\cdot 95}{4\cdot 250}}$	m/sec	4,5
30	Distance at which the maximum concentration discharges X_m is reached $X_m = 20\cdot H = 20\cdot 250$	m	5000

The concentration of impurities C at the unsafe wind velocity u_m at distances different from X_m is determined for different values of X (every 1-2 km) from values of C_m in X_m, calculated from the graph of the relation $\frac{X}{X_m} = f(\frac{C}{C_m})$ illustrated in Fig. 3.

The data obtained are used to plot the graph of the dependence of C_{SO_2} on X and of C_{ash} on X.

Appendix III

Example of the plotting of curves of total residues, of differential distribution curves of dust discharges, and of the auxiliary graph R" = f(R')

The initial carryover composition taken for the calculation is given in Table 2.

Values of the total residues R' and R" are determined from the known composition of the carryover Y' and Y" (Table 3).

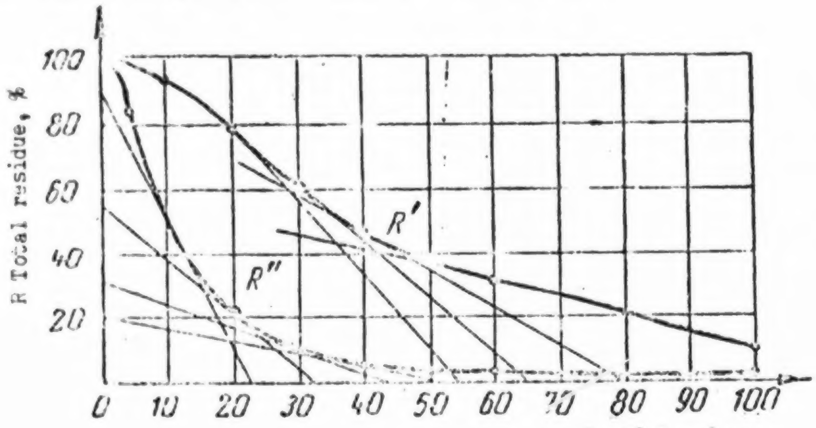

Fig. 1

The curves of residues R' and R" plotted from the values of Table 3 are shown in Fig. 1. The differential distribution curves are plotted by graphical differentiation of the curves R' and R"; the derivative is determined at several points of the curve R' or R". The values of the derivative obtained are laid off along the ordinate axis, and the particle sizes corresponding to it are laid off along the abscissa axis. The distribution curves thus plotted are shown in the graph of Fig. 2.

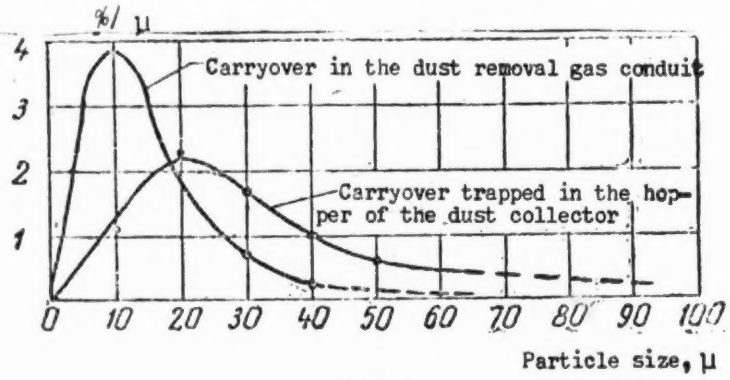

Fig. 2

An example of the plot of the auxiliary graph R" = f(R') necessary for the calculation of the partial degree of gas purification is given in Fig. 3.

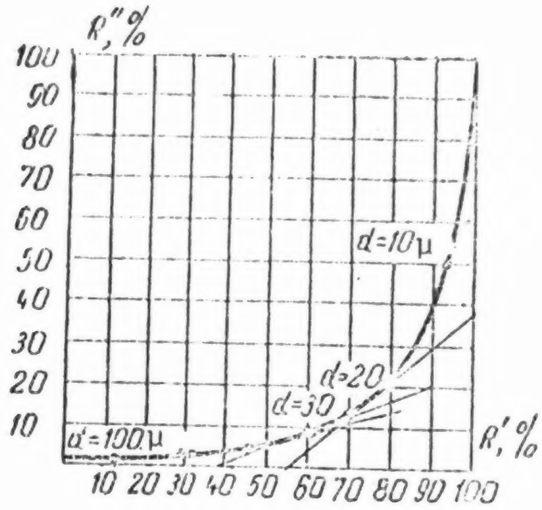

Fig. 3

The values of R" and R' are determined for a series of particle sizes from the graph of curves of total residues (Fig. 1). The values of $\frac{dR''}{dR'}$ for the corresponding particle sizes are determined by a similar method of graphical differentiation of the plotted curve R" = f(R').

An example of a plot of the graph of fractional and partial degree of purification is illustrated in Figs. 4 and 5. The values of the partial degree of purification for different devices are given in Table 4, and approximate values of the total degree of purification in Table 5.

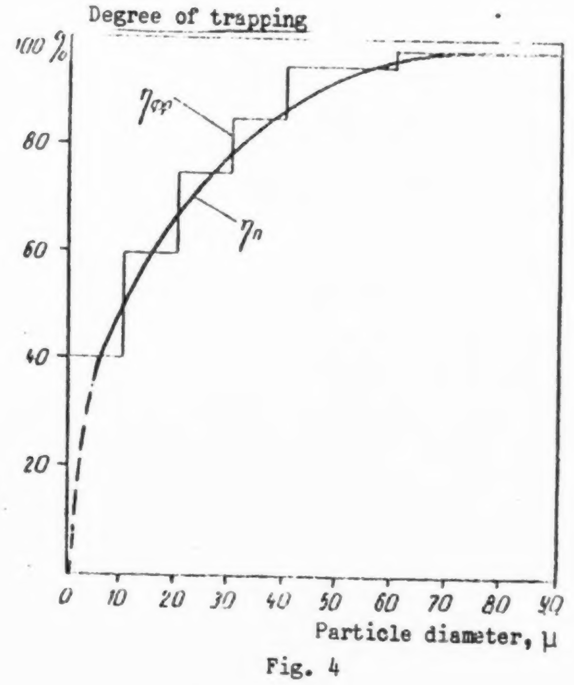

Fig. 4

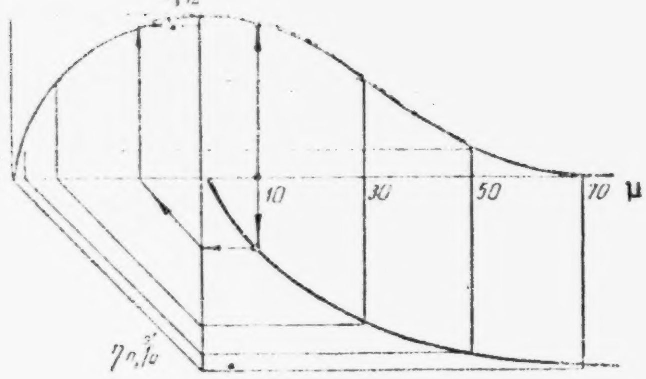

Fig. 5

Table 1

Characteristics of Fly Ash (based on data of the Central Scientific Research Institute for Boilers and Turbines and All-Union Heat Engineering Institute).

Mode of Combustion and Milling	Type of Fuel	Total Residue (%), Particle Size,										Ash Density, g/cm^3
		>0	>5	>10	>20	>30	>40	>50	>60	>80	>100	
1	2	3	4	5	6	7	8	9	10	11	12	13
Powdered-coal (ball-tube mill)	Donets bituminous coal T	100	88	68	37	26	19	15	11	5	3	2,3—2,5
Powdered-coal (ball-tube mill)	Kuznetsk bituminous coal T	100	88	69	38	29	23	18	13	8	5	2,3—2,5
Powdered-coal (ball-tube mill)	Kemerovo bituminous coal	100	92	79	57	40	30	22	16	8	5	2,2—2,4
Powdered-coal (ball-tube mill)	Chelyabinsk brown coal	100	93	82	62	46	37	30	24	13	9	2,3—2,4
Powdered-coal (ball-tube mill)	Moscow brown coal	100	90	71	48	34	26	19	14	5	2	2,2—2,4
Powdered-coal (medium speed mill)	Inta bituminous coal	100	93	80	53	39	30	24	19	11	8	2,2—2,5
Powdered-coal (medium speed mill)	Vorkuta brown coal	100	92	75	40	26	19	15	12	6	4	2,2—2,5
Powdered-coal (medium speed mill)	Tkvarcheli bituminous coal	100	97	91	79	57	41	32	27	15	9	2.4—2,2

Table 1
(Cont'd)

Mode of Combustion and Milling	Type of Fuel	Total Residue (%), Particle Size,										Ash Density, g/cm^3
		>0	>5	>10	>20	>30	>40	>50	>60	>80	>100	
1	2	3	4	5	6	7	8	9	10	11	12	13
Powdered-coal (hammer mill)	Leninskiy bituminous coal	100	96	91	75	53	38	32	26	16	12	2,4—2,
Powdered-coal (hammer mill)	Inta bituminous coal	100	94	79	47	25	16	10	8	4	2	2,2—2,5
Powdered-coal (hammer mill)	Vorkuta brown coal	100	92	75	41	25	13	8	5	3	2	2,2—2,5
Powdered-coal (hammer mill)	Kansk brown coal	100	95	88	66	47	34	24	18	9	6	2,2—2,4
Powdered-coal (hammer mill)	Aleksandriyskiy brown coal	100	94	84	55	35	23	15	11	7	5	2,3—2,4
Powdered-coal (hammer mill)	Gdov Shale	100	93	90	34	19	12	9	7	4	2	2.4—2,5
Powdered-coal (air hammer mill)	Moscow brown coal	100	—	54	35	26	19	14	11	7	4	—
Powdered-coal (hammer mill)	Milled peat	100	—	98	91	74	—	29	—	—	17	—
Powdered-coal (ball-tube mill)	Moscow brown coal (dried)	100	—	54	39	32	25	19	14	6	1	—
Powdered-coal (ball-tube mill)	Donets Ash	100	—	73	51	38	30	24	15	—	—	—

Table 2

Fractional Composition of Ash Carryover.

Carryover	Size of Particle Fractions, μ							
	>0—10	>10—20	>20—30	>30—40	>40—50	>50—60	>60—100	>100
Carryover trapped in the dust collector hopper, Y'%	6,2	14,8	18,4	14,7	8,6	4,9	20,4	12
Carryover in the gas conduit past the dust collector, Y"%	49,1	31,0	10,5	4,4	1,8	1,2	0,4	1,6

Table 3

Values of Total Residues of Ash Carryover

Total Residue	Total Residues (%) for Particles of Size, μ							
	0	10	20	30	40	50	60	[illegible]
Total residue of carryover trapped in hopper, R', %	100,0	93,8	79,0	60,6	45,9	37,3	32,4	12
Total residue of carryover in gas conduit R", %	100,0	50,9	19,9	9,4	5,0	3,2	2,0	1,6

Table 4

Partial Degree of Gas Purification in Different Types of Ash Collectors

Type of Ash Collector	Mode of Combustion	Grade of Fuel	Partial Degree of Gas Purification, %						
			Partial Size, μ						
			5	10	20	30	40	50	60
Type D cyclone	Powdered-coal (ball mills)	Moscow coal	11	38	57	68	82	87	—
NIIOGAZ cyclone	Bed-type	Moscow coal	55	87	97	98	98,5	99	99
Louvered unit of VTI design	Powdered-coal (impact mills)	Moscow coal	29	45	75	91	93	95	—
BTs multicyclone with a 250 mm diameter of elements	Powdered-coal (ball mills)	Moscow coal	64	94	99	—	—	—	—
BTs battery cyclone with a 150 mm diameter of elements	Powdered-coal (ball mills)	Moscow coal	80	94	97	99	—	99	—
Tubular honeycomb electrostatic precipitator of the "Gazoochistka" trust	Powdered-coal (ball mills)	Donets lean coal	92	96	94	88	83	78	72
VTI centrifugal scrubber	Powdered-coal (ball mills)	Aralichevskiy coal	78	87	89	93	95	97	97

Table 5

Degree of Trapping of Ash in Various Ash Collectors

Type of Ash Collector	η_{ac}
Multicyclones	80–85
Wet scrubber (TsS and MP)	80–90
Horizontal electrostatic precipitator	
two-pole	92–94
three-pole	95–98
four-pole	93–99
Combination ash collector: multicyclone - three-pole electrostatic precipitator	98–99

Appendix IV

Example of calculation of parameters of smokestacks for 2400 MW electric power plants.

The calculation is made for the same initial conditions as in Appendix II. Thus, four smokestacks are installed at the plant for the combustion of anthracite culm with $Q^{w}_{std} = 25.10$ MJ/kg, $A^{w} = 16.7\%$, $S^{w} = 1.7\%$, at the rate of 862 t/hr. The excess air at the exit from the stack $\alpha = 1.5$; incompletely burned mechanical component $q_4 = 3\%$; fraction of ash in the carryover $a_c = 0.7$; temperature of flue gases at exit from stack $T_g = 120°C$; temperature of ambient air $T_a = 25°C$; volume of discharged gases $V = 3540\ m^3/sec$. The adopted ash collector is a four-pole horizontal electrostatic precipitator with a degree of collection $\eta_{ac} = 98\%$. In this case, the total discharge of ash into the atmosphere will be $M_{ash} = 687$ g/sec, and the discharge of sulfur dioxide $M_{SO_2} = 8140$ g/sec.

Since $8140 > 2 \times 687$, the calculation of the stack parameters must be carried out with respect to the discharge of SO_2.

The following quantities are assumed: $a_{pow} = 0.005$ rub/kW-hr; $\tau = 7000$ hr; $\mu = 0.85$; $K_c = 80$ rub/kW; $K_{mot} = 15$ rub/kW; $\Pi = 10\%$ for the draft machines; $\beta = 1.3$; $K_g = 1.03$ (Table 4).

1. Costs of draft machines (formula (39))

$$c_{dr} = (0{,}225\cdot 15 + 0.125\cdot 80)\cdot 1.3 + \frac{7000\cdot 0{,}85}{0{,}75}\cdot 0.005 = 46.0\ \frac{\text{rub}}{\text{kW year}}.$$

2. Coefficient C_1

$$C_1 = 1{,}13\sqrt{\frac{V}{n}} = 1{,}13\sqrt{\frac{3540}{4}} = 33{,}6.$$

3. Ratio of the specific gravities of air and flue gases

$$\frac{\gamma_a}{\gamma_g} = \frac{273 + T_g}{(273 + T_a)\cdot K_g} = \frac{273 + 120}{(273+25)\,1{,}03} = 1{,}28.$$

4. Coefficient C is assumed to be equal to 1130.

5. Calculated costs of smokestacks (formula (34))

$$\text{c} = \frac{46,0}{1139}\, 3540\, [w^2 - 15\,(1,25 - 1)\, H] + 0,175 \cdot 4 \times$$

$$\times L \cdot H^q \left(\frac{33,6}{\sqrt{w}} + \Delta\right) - 144\,(w^2 - 4,2\,H) +$$

$$+ 0,7\, L H^q \left(\frac{33,6}{\sqrt{w}} + \Delta\right)$$

6. Using Andreyev's formula for the calculation of the stack height with coefficients given by the Moscow branch of the All-Union State Planning Institute, we have

$$H_{\text{eff}} = \sqrt{\frac{235 \cdot 8140}{16 \cdot 4 \cdot 0,5}} = 245\ м;$$

$$C_2 = \frac{1,9}{1,63 \cdot 4} \cdot 33,6 = 9,8,$$

whence $H = 245 - 9,8\sqrt{w}$.

7. When the "Provisional method" is used for calculating the stack height, the calculation is carried out with the aid of formula (38). Then

$$B_3 = \sqrt{\frac{169 \cdot 8140 \cdot 4}{0,5} \cdot \sqrt[3]{\frac{4}{3540 \cdot 95}}} = 244,$$

where $\Delta T = 120 - 25 = 95\,^\circ\text{C}$.

Thus

$$H = 244\sqrt{m}.$$

8. Taking different values of w, we determine the values of H by using a given method and the values of costs C associated with them. For the case under consideration, the optimum values are:

$$w_{\text{opt}} = 37\ \text{m/sec} \qquad D_{\text{opt}} = 5,5\ \text{m} \qquad H_{\text{opt}} = 214\ \text{m}$$

$$\text{C}_{\text{opt}} = 472\ \text{thousand rubles.}$$

Among stacks of standard dimensions, the one closest to the calculated stack has H = 250 m, D = 6.5 m for w = 27 m/sec. Since the cost of such a stack is much higher than that of the calculated stack, it is recommended that a tube with H = 220 m, D = 6.5 m for w = 31 m/sec be installed.

Table 1

Relationship Between the Number of Power Units and the Number of Stacks

Output of Unit, MW	Steam Capacity of Boiler Unit, t/hr	Number of Units per Stack	
		Typical	Possible
100	320	2	3,4
150	500	2	3,4
200	640	2	3,4
300	950	2	3,4
500	1700	1	2
800	1500	1	2
1000	2800	1	2
	420	4	6,8
	480	4	6,8

Table 2

Empirical Coefficients as a Function of the Adopted Stack Height

H, m	50–110	100–210	190–300
q	2,0	2,5	3,0
Δ	3	3	3
L	$8 \cdot 10^{-1}$	$8 \cdot 10^{-2}$	$7 \cdot 10^{-3}$

Table 3

Fraction of Fuel Ash Carried Out of the Furnace into the Gas Conduit (According to Averaged Data)

Type of Furnace System	a_e
Furnace with cool hopper	0,85
Furnace with warm hopper	0,75
Single-chamber furnace with liquid-bath slag removal	0,60
Twin chambered furnace with liquid-bath slag removal	0,35
Cyclone furnace (horizontal cyclone)	0,10

Table 4

Value of Coefficient K_g for Various Fuels

Fuel	K_g
High moisture brown coal ($W^{red} \geqslant 9.5$)	0,95
Kansk type brown coals	1,00
Bituminous coals and ASh	1,03
Natural gas	0,97
Fuel oil	1,00

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[illegible] THE AGRICULTURAL [illegible]

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A. INTERNATIONAL COOPERATION IN CROP IMPROVEMENT THROUGH THE UTILIZATION OF THE CONCEPT OF AGROCLIMATIC ANALOGUES [illegible]

B. SOME PRELIMINARY OBSERVATIONS ON PHENOLOGICAL DATA AS A TOOL IN THE STUDY OF PHOTOPERIODIC AND THERMAL REQUIREMENTS OF VARIOUS PLANT MATERIAL

C. AGRO-CLIMATOLOGY AND CROP ECOLOGY OF THE UKRAINE AND CLIMATIC ANALOGUES IN NORTH AMERICA

D. AGRO-CLIMATOLOGY AND CROP ECOLOGY OF PALESTINE AND TRANSJORDAN AND CLIMATIC ANALOGUES IN THE UNITED STATES

E. USSR—Some Physical and Agricultural Characteristics of the Drought Area and Its Climatic Analogues in the United States

F. THE ROLE OF BIOCLIMATOLOGY IN AGRICULTURE WITH SPECIAL REFERENCE TO THE USE OF THERMAL AND PHOTO-THERMAL REQUIREMENTS OF PURE-LINE VARIETIES OF PLANTS AS A BIOLOGICAL INDICATOR IN ASCERTAINING CLIMATIC ANALOGUES (HOMOCLIMES)

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